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Application of the IEC 61400-3-1 Standard Design Load Cases to an Offshore Wind Turbine in the Massachusetts Wind Energy Area

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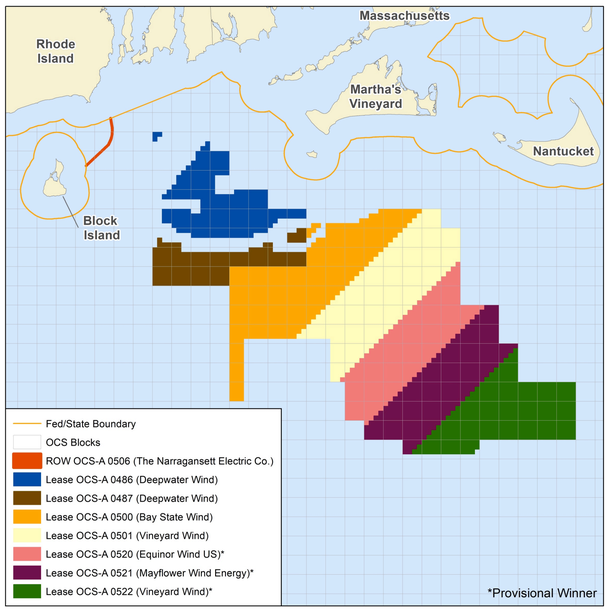
Introduction: Offshore Wind Technical Standards

Fixed bottom offshore wind turbines on jacket structures (left two) and monopile (right turbine) from (1).

- The IEC 61400-3-1 standard for fixed bottom offshore wind turbines was significantly updated in 2013 since to reflect changes in the offshore wind industry
- New projects must be certified from a licensed certification agent that they conform to all requirements of this standard
- No offshore wind turbines have yet been installed in the Massachusetts Offshore Wind Energy Area
- $405 Million has been spent at auctions for undeveloped lease areas



Massachusetts Offshore Wind Lease Areas from (2).

Methodology

- The software FAST was used to run the design load cases on a reduced order simulation model of a 10MW reference wind turbine on a monopile foundation in 40m water depth, representative of the Massachusetts Offshore Wind Energy Area
- Wind files for each case were generated using the software TurbSim
- Wave and currents were generated using FAST module HydroDyn
- Cases were based on representative metocean conditions at a site in the Massachusetts Offshore Wind Energy Area

Design Loading Cases

DLC	Wind Used	Waves Used	Analysis Type	Number of Simulation Runs	Analysis Tool Used
1.1	NTM	NSS	Ultimate	66	MExtremes
1.2	NTM	NSS Joint	Fatigue	1584	MLife
1.3	ETM	NSS	Ultimate	66	MExtremes
1.4	ECD	NSS	Ultimate	66	MExtremes
1.5	EWS	NSS	Ultimate	66	MExtremes
1.6	NTM	SSS	Ultimate	66	MExtremes

Power Production Plus Occurrence of Fault

DLC	Wind Used	Waves Used	Analysis Type	Number of Simulation Runs
2.1	NTM	NSS	Ultimate	66
2.2	NTM	NSS	Ultimate	N/A
2.3	EOG	NSS	Ultimate	18
2.4	NTM	NSS	Fatigue	66
2.5	NWP	NSS	Ultimate	66

Start Up

DLC	Wind Used	Waves Used	Analysis Type	Number of Simulation Runs
3.1	NWP	NSS	Fatigue	66
3.2	EOG	NSS	Ultimate	72
3.3	EDC	NSS	Ultimate	48

Normal Shut Down

DLC	Wind Used	Waves Used	Analysis Type	Number of Simulation Runs
4.1	NWP	NSS	Fatigue	66
4.2	EOG	NSS	Ultimate	108

Emergency Stop

DLC	Wind Used	Waves Used	Analysis Type	Number of Simulation Runs
5.1	NTM	NSS	Ultimate	66

Parked (standing still or idling)

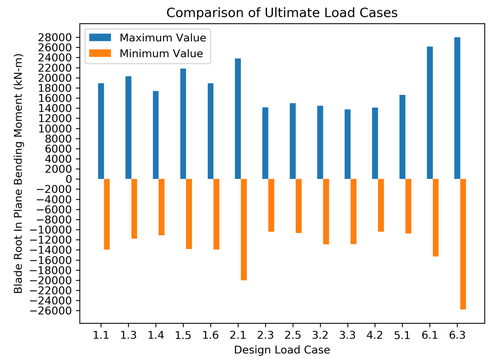
DLC	Wind Used	Waves Used	Analysis Type	Number of Simulation Runs
6.1	EWM	ESS	Ultimate	6
6.2	EWM	ESS	Ultimate	6
6.3	EWM	ESS	Ultimate	6
6.4	NTM	NSS (misalignment)	Fatigue	1584

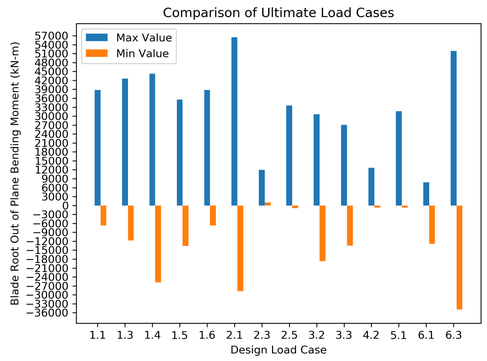
Parameters of Design Loading Cases

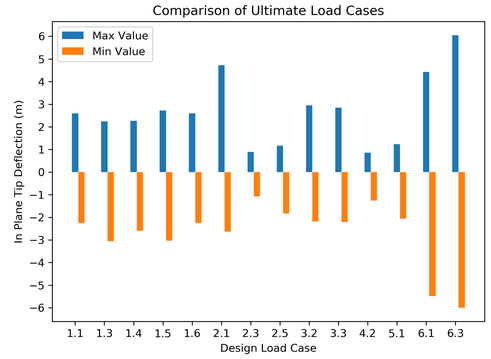
- Wind: Normal Turbulence Model (NTM), Extreme Turbulence Model (ETM), Extreme Coherent Disturbance (ECD), Extreme Wind Shear (EWS), Extreme Operating Gust (EOG), Normal Wind Profile (NWP)
- Wave Conditions: Normal Sea State (NSS), Extreme Sea State (ESS), Severe Sea State (SSS)

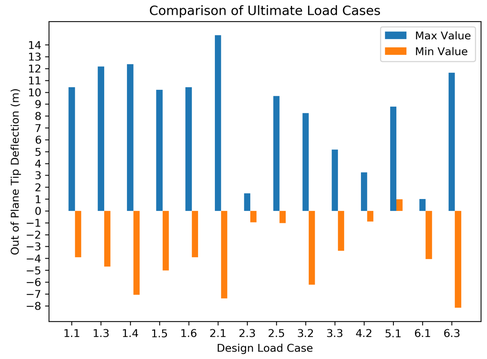
Ultimate Loading Results

- Extreme loads of each case in the positive and negative direction were compared in the four parameters specified by the IEC Standard
- 1. Blade Root Bending Moment in Plane
- 2. Blade Root Bending Moment out of Plane
- 3. In Plane Tip Deflection
- 4. Out of Plane Tip Deflection









- The maximum blade root in plane bending moment in both the positive and negative directions occurs in DLC 6.3, which calls for extreme wind and wave loading at idle combined with a extreme yaw misalignment of the turbine.
- The maximum blade root in plane bending moment in the positive direction occurs in DLC 2.1, which represents a worst-case control system where one blade's pitch control system fails, and the turbine is quickly brought to an emergency stop. The maximum blade root in plane bending moment in the negative direction occurs in DLC 6.3.
- The maximum in plane tip deflections in both the positive and negative direction occur in DLC 6.3.
- The maximum positive out of plane tip deflection occurs in DLC 2.1, and the maximum negative out of plane tip deflection occurs in DLC 6.3.

Future Work

- IEC Standard load cases for an offshore turbine on a floating platform will be analyzed.
- Hurricane loading cases should be systemically analyzed in greater detail for the US offshore case, especially considering the possibility of compounding events such as loss of electrical system during a storm.

References

1. https://www.energy.gov/eere/articles/us-conditions-drive-innovation-offshore-wind-foundations
2. 2. https://www.boem.gov/state-activities-massachusetts/
3. IEC 61400-3-1
4. Definition of Meteorological Conditions for Applying IEC 61400-3-1 to an Offshore Wind Turbine in the Massachusetts Offshore Wind Energy Lease Areas