Learning from the Experts Webinar Series

Offshore Wind Resiliency Planning

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Senior Energy Resilience Expert
ICF

Garrett Moran
Wind Generation Senior Manager
ICF

July 7, 2021
Meeting Procedures

Webinar recordings and presentations will be available at:
www.nyserda.ny.gov/osw-webinar-series

Participation for Members of the Public:

> Members of the public will be muted upon entry.

> Questions and comments may be submitted in writing through the Q&A feature at any time during the event.

> If technical problems arise, please contact Sal.Graven@nyserda.ny.gov
Learning from the Experts

This webinar series is hosted by NYSERDA’s offshore wind team and features experts in offshore wind technologies, development practices, and related research.

DISCLAIMER:
The views and opinions expressed in this presentation are those of the presenter and do not represent the views or opinions of NYSERDA or New York State.
• Meet your presenters and ICF
• The role of offshore wind in meeting climate goals
• Offshore wind basics
• How climate impacts offshore wind performance and reliability
• Projected changes to climate by mid-century
• Building resilience of offshore wind systems
Your Presenters

Neil Weisenfeld
Senior Energy Resilience Expert
Neil.Weisenfeld@icf.com

Garrett Moran
Wind Generation Senior Manager
Garrett.Moran@icf.com
Who is ICF?

Washington, DC area
- corporate headquarters

70
- offices worldwide

7,000+
- employees

$1.4+ billion
- revenue

Energy

Environment

Transportation

Technology & Cybersecurity

Health
The NYS Climate Leadership and Community Protection Act (CLCPA), passed in 2019, sets ambitious goals to decarbonize the electric grid, heating and transportation systems while improving energy resilience, affordability and supporting the New York economy.

- **2025**: 6,000 MW Solar
- **2030**: 70% Renewable Energy
- **2035**: 3,000 MW Energy Storage
- **2035**: 9,000 MW Offshore Wind
- **2040**: 100% Zero-emission Electricity
- **2050**: 85% Reduction in GHG Emissions

→ The NYS CLCPA advances ambitious climate goals
• Carbon free source of energy that help mitigate climate change
• Higher energy output than onshore wind because of stronger offshore winds
• Improves local air quality by reducing emissions from fossil units
• Easier to site and less disruptive to communities than onshore wind
• Generates economic growth – estimated at 100,000 jobs and billions in investment to NYS

→ Benefits of Offshore wind
East coast offshore wind potential is greatest from the New Jersey coast to the Gulf of Maine

Source: DOE EERE, 2016
a) Wind turbine generator and fixed support structures
b) Submarine cable collecting array
c) Export cables
d) Transformer stations – increase voltage
e) Offshore stations - may include A.C. to D.C. conversion
f) Meteorological masts
g) Onshore stations – transmit energy to grid, may include D.C. to A.C. conversion.

* Port infrastructure to facilitate staging assembly and installation of Offshore Wind (OSW) systems (not shown)

→ **Offshore Wind System**

Source: Rodriguez, et. al., 2016
• Blades have lifting body shape (airfoil)
• Air flow over airfoil creates lift on suction side
• Lift rotates the rotor, which is rigidly connected to the drivetrain
• In geared systems, the drivetrain torque is up-converted in gearbox to high-speed rotation for generator, which makes electricity
• Direct drive generators, often used in offshore wind turbines, can generate electricity at much lower rotational speeds than geared systems

→ How Does a Turbine Work?

Ref:
http://www.cleanenergybrands.com/shoppingcart/knowledgemanager/questions/157/101+renewable+small+wind+turbines
Ref: http://www.cleanenergybrands.com/shoppingcart/knowledgemanager/questions/157/101+renewable+small+wind+turbines
<table>
<thead>
<tr>
<th>Climate Stressor</th>
<th>Wind Turbine Generators</th>
<th>Support structures*</th>
<th>Collecting and export cables</th>
<th>Onshore stations</th>
<th>Ports</th>
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<td>Extreme wind</td>
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<td>Storm surge</td>
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<td>Hacking</td>
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<td>Vandalism</td>
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</table>

*Includes support structures for wind turbine generators and offshore stations

→ **Summary of Climate Risk Factors to OSW**
• Wind Class I, II, III based on reference wind speed
  • \( V_{\text{ref}} \approx 5 \times V_{\text{ave}} \)

• \( I_{\text{ref}} \) is the reference turbulence intensity

• \( V_{\text{ref,T}} \) is the reference wind speed for a tropical cyclone, typhoon, or hurricane

<table>
<thead>
<tr>
<th>Wind Class</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{\text{ref}} ) (m/s)</td>
<td>50</td>
<td>42.5</td>
<td>37.5</td>
</tr>
<tr>
<td>( V_{\text{ave}} ) (m/s)</td>
<td>10</td>
<td>8.5</td>
<td>7.5</td>
</tr>
<tr>
<td>( V_{\text{ref,T}} ) (m/s)</td>
<td>57</td>
<td></td>
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</tbody>
</table>

\( A \) \( I_{\text{ref}} \) | 0.16 |
\( B \) \( I_{\text{ref}} \) | 0.14 |
\( C \) \( I_{\text{ref}} \) | 0.12 |

\[ \text{IEC 61400-1 Wind Classes} \]
- Addresses all marine-related design considerations
- Hydrodynamic loading is accounted for
  - Wind + Wave and Current

**IEC 61400-3 Offshore Turbine Design**
<table>
<thead>
<tr>
<th>Climate Factor</th>
<th>Considerations</th>
<th>Relative impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed and consistency</td>
<td>• Turbine output varies with the cube of wind speed so small changes in speed</td>
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<tr>
<td></td>
<td>significantly impact output</td>
<td></td>
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<tr>
<td>Wind direction</td>
<td>• Consistent direction improves efficiency and capacity factor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Shifting winds can increase wear and tear on components</td>
<td></td>
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<tr>
<td>Turbulence intensity and wind</td>
<td>• Smoother, less turbulent wind improves output</td>
<td></td>
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<tr>
<td>shear</td>
<td>• Vertical shear has a small impact on output, depending on surface roughness</td>
<td></td>
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<tr>
<td>Air temperature</td>
<td>• Increases in air temperature can reduce turbine power output due to reduced</td>
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<tr>
<td></td>
<td>density of air</td>
<td></td>
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<tr>
<td></td>
<td>• A 5-degree increase would result in a 1 – 2% decrease in turbine output</td>
<td></td>
</tr>
<tr>
<td>Air moisture and precipitation</td>
<td>• Moisture has the potential to increase the erosion on the leading edges of turbine blades, requiring more frequent maintenance</td>
<td></td>
</tr>
</tbody>
</table>

→ Factors Impacting OSW Performance
<table>
<thead>
<tr>
<th>Climate Factor</th>
<th>Considerations</th>
<th>Relative impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winds above operating limit</td>
<td>• High winds above design operating limit may require turbines to shut down</td>
<td></td>
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<tr>
<td>Ocean waves</td>
<td>• Can affect undersea cables and mooring lines</td>
<td></td>
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<tr>
<td></td>
<td>• Waves directly impact foundation and support structures</td>
<td></td>
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<tr>
<td>Frozen precipitation</td>
<td>• Build up on blades can cause weight imbalances requiring shutdown</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• May directly damage turbine blades</td>
<td></td>
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<tr>
<td>Extreme storms</td>
<td>• Accounted for in design standards but storms outside of standards have caused</td>
<td></td>
</tr>
<tr>
<td></td>
<td>shutdowns and damaged turbines in the past</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• May also damage undersea infrastructure due to wave action</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• May impact coastal onshore infrastructure such as substations and ports</td>
<td></td>
</tr>
<tr>
<td>Sea level rise</td>
<td>• Could cause water damage and corrosion of components</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• May exceed mooring line or tether tension limits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• May impact vertical wind profile and turbine shear loading, increasing wear and tear</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• May impact coastal onshore infrastructure such as substations and ports</td>
<td></td>
</tr>
</tbody>
</table>

**Factors Impacting OSW Reliability**
<table>
<thead>
<tr>
<th>Climate Factor</th>
<th>Outlook</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed, shear and geographic distribution</td>
<td>Uncertain</td>
<td>• Global wind speeds declined after the 1970’s but increased beginning in 2010. Current thinking points to decadal variations in speed.</td>
</tr>
</tbody>
</table>
| Temperature                       | Increase      | • The projected increase of 3-5.5 degrees would reduce turbine output.  
• Temperature increases may however invigorate sea breezes, counteracting output reductions. |
| Hurricanes                        | The same number but Increase in intensity | • Warming waters hold more energy, supporting an increase in hurricane intensity.  
• The number of hurricanes in the North Atlantic is projected to remain the same or slightly diminish but the frequency of the strongest hurricanes is projected to increase.  
• Hurricane tracks may move offshore, more directly impacting OSW. |
| Nor’easters                       | Increase in frequency and intensity | • Potential 10% to 40% increase in frequency of very strong storms and greater concentration of storms along the coast. |
| Precipitation                     | Increase in frequency and magnitude | • Projected 20% to 40% increase in the amount of precipitation during heaviest events.  
• Projected decrease in the frequency of frozen precipitation but the increases in storm strength may result in an overall increase in icing. |
| Sea level rise and storm surge    | Increase      | • Up to 30 inches of sea level rise by mid-century.  
• Hurricane tracks shifting further off-shore may moderate increases in storm surge. |

Projected Changes to Northeast Climate Factors by Mid-Century
<table>
<thead>
<tr>
<th>Wildlife Impact</th>
<th>Outlook</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avian wildlife</td>
<td>Stable</td>
<td>• Wind power has less than 3% of the avian fatalities per GWh of those associated with fossil fuel generation&lt;br&gt;• The location of the NYS wind farms at greater than 14 miles offshore, significantly reduces the risk to Avian species</td>
</tr>
<tr>
<td>Marine wildlife</td>
<td>Stable</td>
<td>• Underwater vibration can disturb wildlife, particularly during construction&lt;br&gt;• No consensus on whether climate change impact on acoustic properties will be meaningful</td>
</tr>
<tr>
<td>Turbine sound</td>
<td>No known or identified impact to-date</td>
<td>• Wind farms are far enough offshore to be imperceptible and future increases in ambient temperature are unlikely to change perceptibility</td>
</tr>
</tbody>
</table>

→ Offshore Wind, Climate Change, and Impacts on Wildlife and Communities
Changing Wind Speeds
• Vortex generations (VGs), gurney flaps, stall strips, aeroelastically tailored blades
• Microtabs, flaps, LIDAR
• More robust designs, increased international design standards

Changing Wind Direction
• Improved and more robust pitch and yaw systems
• Blades designed to operate in a larger range of angles of attack
• Increased O&M

Changing Wind Shear
• Taller towers (vertical shear)
• LIDAR with robust pitch and yaw systems (horizontal shear)

→ Turbine Resiliency to Changing Wind Speed, Direction, and Shear
• Ridges or fins on suction side of blade (top) to maintain flow attachment along blade chord
• Used to boost power and improve performance, but results in increased loads

Vortex Generators

Ref: http://powercurve.dk/our-technology/
Ref: https://www.sparesinmotion.com/wind-turbine-parts/blade-parts/vortex-generator-for-different-technologies-lm-aerpac-vestas-siemens
• Added to the trailing edge of the blade
• Increases pressure on the suction side of the blade
• Decreases pressure on the low-pressure side
• Helps maintain boundary layer attachment to trailing edge

• Act as chord extenders on inboard span, working to improve aerodynamic performance
• Can also delay stall

→ **Gurney Flaps**

Ref: [https://www.researchgate.net/figure/Active-Gurney-Flap-or-Micro-Tab-for-load-alleviation_fig28_307960051](https://www.researchgate.net/figure/Active-Gurney-Flap-or-Micro-Tab-for-load-alleviation_fig28_307960051)

Ref: [https://www.researchgate.net/figure/Schematic-showing-the-physical-effect-of-the-Gurney-flap-on-the-trailing-edge-region_fig1_328329783](https://www.researchgate.net/figure/Schematic-showing-the-physical-effect-of-the-Gurney-flap-on-the-trailing-edge-region_fig1_328329783)
• Couples flap or edge DOF with torsion
• Two main methodologies
  • Physical sweep curvature
  • Material coupling through off-axis fiber orientations

Aeroelastic Tailoring

Ref: https://www.semanticscholar.org/paper/AEROELASTIC-TAILORING-IN-WIND-TURBINE-BLADE-1-co-4-Veers-Gunji/ddca71e6dddf1462d6ebd1a62e426f930e1291c


Ref: https://www.sciencedirect.com/science/article/abs/pii/S0960148114003115

Ref: https://www.semanticscholar.org/paper/AEROELASTIC-TAILORING-IN-WIND-TURBINE-BLADE-1-co-4-Veers-Gunji/ddca71e6dddf1462d6ebd1a62e426f930e1291c
• Technologies to actively adjust the air flow over the blade
  • Microtabs
  • Synthetic jets
  • Stall strips

Ref: [https://www.pinterest.com/pin/781023760356163549/](https://www.pinterest.com/pin/781023760356163549/)

→ Active Load Control

• LIDAR allows the turbine to “see” the wind up-stream and make corrective actions before the wind crosses the rotor disk
• Part of a feed-forward control loop
• Becoming more common

LIDAR (Light Detection And Ranging)

Ref:
https://www.aist.go.jp/fukushima/en/unit/WPT_e.htm

Ref:
https://www.researchgate.net/figure/left-Ground-Doppler-lidar-system-installed-in-a-wind-farm-right-Taking-advantage_fig3_316715802
• Similar to airplane wing trailing edge flaps, allows the turbine to actively control the loads on individual blades
• Not widely used
  • Requires a lot of maintenance
  • Complex mechanisms that can break

→ Active Flaps
Wave Loading

• Robust fixed foundation designs to withstand potential of increased wave loading
• Heavier and more massive foundations, increased foundation bolts
• Ensure design lengths of cables, tethers, and mooring lines are sufficient for increased sea level and variability

Sea Level Rise

• Likely minimal impact to offshore wind
• Design elevations of future turbines to account for increased sea level and variability

→ **Turbine Resiliency to Sea Level Rise and Wave Loading**
• Increased severity and frequency of extreme weather should be incorporated into future international design standards
• Heavier and stiffer blades
• Stronger and more robust pitch and yaw systems
• Split pitch systems
• Two-bladed offshore designs
• Down-wind designs

Turbine Resiliency to Extreme Weather

Ref: https://www.windpowermonthly.com/article/1227512/close-up-envisions-en128-36me-direct-drive-turbine
Ref: https://en.wikipedia.org/wiki/Yaw_system
- Hydrophobic blade coatings and paint
- De-icing and anti-icing weatherization technologies
- Real-time health monitoring and remote sensing

Turbine Resiliency to Precipitation

Ref: https://www.researchgate.net/figure/Ice-on-a-wind-turbine-blade-10_fig5_334175712
Ref: https://windfair.net/wind-energy/news/16991-slips-coating-technology-against-ice-build-up-on-offshore-wind-turbines
<table>
<thead>
<tr>
<th>Climate Factor</th>
<th>Resilience Options</th>
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<tbody>
<tr>
<td>Sea level rise and coastal storms</td>
<td>• Elevating infrastructure</td>
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<td></td>
<td>• Storm resilient sea walls and piers</td>
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<td></td>
<td>• Nature based solutions such as wetlands and oyster reefs</td>
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<tr>
<td></td>
<td>• Waterproofing facilities</td>
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<tr>
<td>Precipitation</td>
<td>• Drainage systems</td>
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<tr>
<td></td>
<td>• Porous paved surface technologies to absorb water</td>
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<td></td>
<td>• Green infrastructure to help manage rainwater and runoff</td>
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<tr>
<td>Increasing temperature</td>
<td>• Higher temperature materials</td>
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<td></td>
<td>• Increasing tree and vegetation cover to reduce surface temperature</td>
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<td></td>
<td>• Green and reflective roofs</td>
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<td></td>
<td>• Cool pavements</td>
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<tr>
<td>High winds</td>
<td>• Upgrade existing structures consistent with expected peak winds</td>
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<td></td>
<td>• Incorporate future wind projections into the design of new structures</td>
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</tbody>
</table>

→ Building the Resilience of Coastal Infrastructure

Offshore wind systems are currently designed to withstand many climate hazards, including extreme winds and storm surge.

Climate change has the potential to stretch design and operational limits.

Designers and operators have a range of options to build resilience of OSW systems.

Some of these options are commercially available today, while others will require continued development.

By monitoring emerging climate science and technologies, designers can incorporate appropriate resilience options into future OSW systems.

### Summary of Climate Risk Factors to OSW and Conclusions

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</table>

*Includes support structures for wind turbine generators and offshore stations

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[Table with color codes for low, medium, and high risk]
Backup Slides
• IEC 61400-1 – Onshore turbine design spec
• IEC 61400-3 – Offshore turbine design spec
• And many others...

• Many companies issue turbine certifications
  • DNV GL
  • Lloyd’s Register
  • Technischer Überwachungsverein (TUV)
  • UL
  • CGC (China)
  • And more...

→ Design Specifications and Requirements
• Design Load Cases
  • DLC 1.X – Power production
  • DLC 2.X – Power production with faults
  • DLC 3.X – Start up
  • DLC 4.X – Shut down
  • DLC 5.X – Emergency stop
  • DLC 6.X – Parked and idle
  • DLC 7.X – Parked and idle with faults
  • DLC 8.X – Transportation and erection
  • Extreme (ULS) and Fatigue (FLS)
  • DLCs consider 1 fault deep failure

IEC 61400-1 – Onshore

Turbine Design
Coming Next:

July 28, 1:00 p.m. ET
Offshore Wind Stakeholder Engagement
Kris Ohleth, Special Initiative on Offshore Wind

August 11, 1:00 p.m. ET
Offshore Wind COP Review Process
Michelle Morin and Jessica Stromberg, BOEM

We want your feedback! Send suggestions for future webinar topics to offshorewind@nyserda.ny.gov.

Visit wind.ny.gov to register