Mid-Atlantic Offshore Wind
Metocean Design Environment

Briefing

Society of American Military Engineers

Hampton, VA

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Nautical Chart Showing Commercial Wind Energy Area (WEA) and two Research Leases

Research Lease 1 for monitoring commercial project development area

Research Lease 2 for demonstration turbines and for validating remote metocean & environmental monitoring instrumentation
Virginia WEA Leased One Month after RI-MA AMI

Deepwater commercial lease effective date: 01 Oct 2013

Dominion commercial lease effective date: 01 Nov 2013
Dominion’s Virginia Offshore Wind Demonstration and Commercial Project Footprints

Commercial project area may contain anywhere from 230 to 330 6-MW turbines depending on spacing for maximum cost-effectiveness and minimum environmental impact (1,400 to 2,000 MW)

Two 6-MW demonstration turbines
Metocean Measurement and Modeling
Historical Hurricane Tracks within 100 km of Virginia Offshore Wind Energy Area
Offshore Extrapolation of ASCE 7-10 Building Standard 50-Year Return Period Gust Speed

IEC Class I turbine design also may not be adequate for 50-yr hurricane wind speeds in RI or MA Wind Energy Areas, and may be marginally adequate for Virginia Wind Energy Area.
## Comparison of Relevant Reference Wind Speeds

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IEC Class I Turbine Design</th>
<th>IEC Class II Turbine Design</th>
<th>Category 2 Hurricane Range</th>
<th>ASCE 7-10 Building Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Wind Speed native units (derived units)</td>
<td>50 m/s (112 mph) ( 97 kt)</td>
<td>42.5 m/s (95 mph) ( 83 kt)</td>
<td>96 – 110 mph (43 – 49 m/s) (83 – 96 kt)</td>
<td>100 – 110 mph (44 – 49 m/s) (87 – 96 kt)</td>
</tr>
<tr>
<td>Reference Wind Speed Averaging Period</td>
<td>10-minute mean</td>
<td>10-minute mean</td>
<td>1-minute sustained</td>
<td>3-sec gust</td>
</tr>
<tr>
<td>Multiplier to Estimate 10-minute Mean *</td>
<td>50 m/s</td>
<td>42.5 m/s</td>
<td>0.93</td>
<td>(1.11/1.23 = 0.90)</td>
</tr>
<tr>
<td>Estimated 10-Minute Mean Wind Speed at Hub Heights: 90 m &amp; 100 m **</td>
<td>50 m/s</td>
<td>42.5 m/s</td>
<td>47.6 – 54.5 m/s</td>
<td>48.5 – 55.0 m/s</td>
</tr>
</tbody>
</table>

* See next slide for WMO tropical cyclone gust factors at 10 m height above ground.

For both hurricanes and nor′easters, estimated fundamental wind and wave parameters at 50- and 100-year return periods

- **Fundamental wind parameter is 10-minute average wind speed at meteorological “surface” elevation of 10 meters above sea level (U10)**
- **Fundamental wave parameter is the significant wave height (Hs) for an assumed 3-hour sea state duration**

From these fundamental parameters, existing and proposed standards specify derived wind and wave conditions to be used in various Design Load Cases (DLCs)

- A “reference” 10-minute mean wind speed (Vref) at turbine hub height is derived from U10 and an assumed vertical profile of wind speed
- Various multipliers of Vref, as specified in the applicable standard, are then used to derive estimates of “extreme” or “reduced” 3-second gust speeds to be used in the DLCs
- Various multipliers of Hs, as specified in the applicable standard, are used to derive estimates of “extreme,” “severe” and “reduced” individual waves and the sea state as a whole
Measured & WIS-Hindcast Significant Wave Heights off Delaware in 1998

NDBC Station 44009 Sig Wave Heights 1998

- NDBC
- NDBC events
- WIS
- WIS events
Measured & WIS-Hindcast Significant Wave Heights off Delaware in 1999

NDBC Station 44009 Sig Wave Heights 1999

- NDBC
- NDBC events
- WIS
- WIS events

Sig Wave Height (m)

Month

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Hurricane Hazard Model Overview

- Two Main Model Components
  - *Hurricane hazard simulation model (track, intensity and frequency)*
    - Probabilistic models for Radius to maximum winds and the Holland B parameter
  - *Wind field and wave models*

- Published in the peer reviewed open literature
  - 3 papers in meteorological journals (filling model, B and RMW models, and wind field model)
  - 4 papers in engineering journals (stochastic model methodology and wind field model)
  - *First ever track model*
  - *First model to model B as a random variable*

- Wind field model extensively validated
- Used in FEMA coastal flood studies
- Used in FEMA’s Hazus loss estimation tool HAZUS
Simulation Methodology

Step 1: Initialize Storm Sample B and RMW error term
Compute P_c, B, RMW
Step 2: 5" Squares Sample new $\theta$ and $V_t$
Compute new value of I
Compute $P_c, B, RMW$
Step 3: Storm Filling Central pressure filling (Vickery, 2005)
Site Lat and Long Distance inland vs. direction
Step 4: Windfield model (Vickery et al. 2008) turned on if storm within 250 km of site
$V = f(P_c, B, RMW, V_t, r)$
Central Pressure (6 hour interval)
Hurricane Wind Hazard Curve at CHLV2

Setting Up the Coupled Wind and Wave Design Load Cases
Both the IEC 61400-3 and the ABS BOWTI standards specify Design Load Cases (DLCs) for combined wind and wave loading by assuming that for a given design storm, the peak 3-second gust and the maximum individual wave height would not occur at the same instant at a given turbine location. They therefore specify two combined DLCs:

- **Extreme wind with reduced wave** (e.g., DLC 6.1b): the peak 3-second gust at hub height is combined with a “reduced” individual wave height that is lower than the maximum individual wave

\[
V_{gust,\text{max}} = 1.4 \ V_{\text{ref 10 min}} \quad \quad H_{\text{reduced}} = 1.3 \ H_s
\]

- **Extreme wave with reduced wind** (e.g., DLC 6.1c): the maximum individual wave height is combined with a “reduced” 3-second gust speed that is slower than the peak gust

\[
V_{gust,\text{reduced}} = 1.1 \ V_{\text{ref 10 min}} \quad \quad H_{\text{max}} = 1.86 \ H_s
\]
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Is this the right multiplier and what kind of wave is it?
Comparing SHM-SWAN Wind & Wave Hazard Curves across Virginia Nearshore Shelf

WIS grid point nearest to wind and wave measurement validation stations

WIS grid point nearest to Virginia Offshore Wind Technology Advancement Project

Legend:
- Fixed platform metocean measurement station
- Moored buoy metocean measurement station
- Corps of Engineers WIS hindcast grid points
- Oceanweather EC28km hindcast grid points
- Virginia Wind Energy Area
- DMME Research Lease 2
Significant Wave Height Hazard Curve and Associated Mean Surface Wind Speeds at WIS 63197

WIS #63197 depth = 17m

100-yr Hs = 5.9 m
1,000-yr Hs = 6.1 m

Significant Wave Height Hazard Curve and Associated Mean Surface Wind Speeds at WIS 63196

WIS #63197 depth = 20m

- 100-yr Hs = 8.4 m
- 1,000-yr Hs = 8.6 m

What is Limiting Extreme Wave Heights?
Major Hurricane Isabel

Dates: 09/06 - 09/20 2003
Maximum Wind Speed: 165 mph
Minimum Pressure: 915 mb
US Landfall Category: Category 2 Hurricane
Deaths: 17
US Damage (Millions US $): 5370

Storm Category

<table>
<thead>
<tr>
<th>Category</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>mph</td>
<td>74-95</td>
<td>96-110</td>
<td>111-130</td>
<td>131-155</td>
<td>156+</td>
</tr>
<tr>
<td>mph</td>
<td>&lt;39</td>
<td>39-73</td>
<td>74-95</td>
<td>96-110</td>
<td>111-130</td>
</tr>
</tbody>
</table>

Sep 2003 Hurricane Isabel Track & Satellite Image
Sep 2003 Hurricane Isabel SWAN Modeling
Wind Speed Validation (Jeff Hanson & colleagues)

HWind swath map from http://hwind.co/legacy_data
Sep 2003 Hurricane Isabel SWAN Modeling
Wave Height Validation (Jeff Hanson & colleagues)

HWind swath map from http://hwind.co/legacy_data
SWAN modeled wave dissipation during Sep 2003 Hurricane Isabel at storm peak $H_s$
- JONSWAP bottom friction, $C_{f_{JON}} = 0.038$
- Westhuysen et al (2007)* whitecapping
- Surf breaking at $\gamma = H_{max}/d = 0.73$


**Comparison of Dissipation Source Terms at Common Scale**
Instance of Wave Breaking at FINO-1

Storm Event October 2009

Time lapse of breaking wave in 28 m depth at FINO-1 platform in North Sea; significant wave height = 5.2 to 5.3 m
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Storm Event October 2009

Time lapse of breaking wave in 28 m depth at FINO-1 platform in North Sea; significant wave height = 5.2 to 5.3 m
Thank You!

Any questions?

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