Offshore Wind Turbines: Extreme Wind/Wave Risk and Regulatory Needs

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Introduction

• MMI executing a Joint Industry Project on comparing IEC design guidelines for offshore wind turbine to API offshore platform guidelines
  – Guideline comparison for design aspects covered
  – Reliability assessment using both
    • For generic structure at a site
    • For generic structure at multiple offshore sites using local metocean risk
    • For two specific offshore wind turbine designs (monopile and multipile) at multiple offshore sites using local metocean risk

• Will offer stakeholders insights into inherent target reliabilities of API and IEC guidelines
Offshore Wind Energy Potential
Wind: Source of Power & Threat

3.6MW Turbine cut out speed: 27 m/s = 60 mph
### Past Hurricanes near Coast

<table>
<thead>
<tr>
<th>Category</th>
<th>Winds (mph)</th>
<th>Winds (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS</td>
<td>39-73</td>
<td>17-33</td>
</tr>
<tr>
<td>1</td>
<td>74-95</td>
<td>33-42</td>
</tr>
<tr>
<td>2</td>
<td>96-110</td>
<td>43-49</td>
</tr>
<tr>
<td>3</td>
<td>111-130</td>
<td>50-58</td>
</tr>
<tr>
<td>4</td>
<td>131-155</td>
<td>59-69</td>
</tr>
<tr>
<td>5</td>
<td>156+</td>
<td>70+</td>
</tr>
</tbody>
</table>

- Category 3-5 storm track
- Category 1-2 storm track
- Tropical storm track
- Tropical depression track
- Subtropical storm track
- Subtropical depression track
- Extratropical storm track
- Tropical low track
- Tropical wave track
- Tropical disturbance track
Recent Hurricanes Hanna, Ike

Risk to coastal infrastructure
What Risk Threshold to Adopt?

• Gulf of Mexico metocean risk being revisited
• The 100-year wave few years ago may no longer be so
  – Indications: In Central Gulf, threat may be much higher (→ 100-year wave height much larger)

• Strategy
  – Decide risk/reliability threshold to adopt for US
  – Devise design “recipe” that ensures threshold or better

• High investment, new technology warrant design to higher risk threshold
Reliability via Recipe

• Metocean conditions – use defined hazard
  – E.g., use an X-year wave, wind, current, etc.

• Design structure with strength and load per recipe (i.e., use implicit safety factors)
  – Implies achievement of target reliability

• Check Reserve Strength (ratio of collapse to design load)
  – High reserve strength implies higher reliability
  – Redundancy in system generally contributes to higher reliability

• 100- or 50-year wave/wind design alone does NOT achieve target reliability
MMS Specific Issues/Concerns

• 50 Year vs. 100 Year Return Periods
  – US offshore facilities generally use 100-year (is current public perception of structural safety)

• US offshore environmental risk different than North Sea and different in NE US vs. GoM

• Fundamental need: Ensure that offshore turbines can withstand extreme storm/hurricane conditions
Background to API RP-2A

- Used to design > 7000 structures!

<table>
<thead>
<tr>
<th>Hurricanes</th>
<th>Hilda</th>
<th>Camille</th>
<th>Juan</th>
<th>Andrew</th>
<th>Lili</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP 2A Edition</td>
<td>1st</td>
<td>9th</td>
<td>20th Supplement 1 Section 17</td>
<td>21st</td>
<td>Reassess 100-year Criteria?</td>
</tr>
</tbody>
</table>

- Ivan
- Katrina
- Rita
Approach of API RP-2A

• Targeted at offshore oil & gas structures
• Design procedures for structure & foundation
• Methods to calculate loads & structural capacity
• Provides wind & wave data for continental U.S.
API RP-2A does not address...

- Turbine-specific design load cases
- Wind fatigue loading
- Soil-structure interaction for large diameter piles
- Grouted connections carrying significant moment load
Approach of IEC 61400-3

• Comprehensive set of design load cases for turbine support structure
• Uses a Partial safety factor format
• Does not address structural capacity
• Does not provide regional environmental data
• Refers to other codes for turbine machinery & design checks
## External conditions: Sea states

<table>
<thead>
<tr>
<th>External condition</th>
<th>API RP-2A</th>
<th>IEC 61400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave height</td>
<td>100 years</td>
<td>nominally 50 years</td>
</tr>
<tr>
<td>return period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave theories</td>
<td>Same: Stokes 5\textsuperscript{th} &amp; Stream function</td>
<td></td>
</tr>
<tr>
<td>Breaking waves</td>
<td>No guidance</td>
<td>Spilling &amp; plunging</td>
</tr>
<tr>
<td>Storm surge</td>
<td>Specified for GoM</td>
<td>Required, not given</td>
</tr>
<tr>
<td>Current profiles</td>
<td>Tidal</td>
<td>Tidal, wind &amp; surf</td>
</tr>
<tr>
<td>Current velocities</td>
<td>Partially specified</td>
<td>Specified</td>
</tr>
</tbody>
</table>
## External conditions: Wind

<table>
<thead>
<tr>
<th></th>
<th>API RP-2A</th>
<th>IEC 61400</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Averaging period</strong></td>
<td>3s, 5s</td>
<td>3s</td>
</tr>
<tr>
<td><strong>Reference height</strong></td>
<td>10m</td>
<td>Hub height</td>
</tr>
<tr>
<td><strong>Shear profile</strong></td>
<td>Log</td>
<td>Exponential</td>
</tr>
<tr>
<td><strong>Turbulence</strong></td>
<td>Log law</td>
<td>Exponential law</td>
</tr>
<tr>
<td><strong>Turbulence</strong></td>
<td>1 point, 1 component</td>
<td>Various 3 component</td>
</tr>
<tr>
<td><strong>Gust specification</strong></td>
<td>Stochastic</td>
<td>Stochastic &amp; Determ.</td>
</tr>
</tbody>
</table>
Japanese Experience

Miyako region – All 7 turbines failed in typhoon Maemi (2003) (Gust 74.1 m/s)

NOTE:
• Turbine failure rate in Japan is 3 times that of Denmark
• Gust winds experienced about 7 times larger than IEC guidelines
Source: Suguro (MHI)
Formulation of Structural Reliability

(Elementary case)

Mean Load

Mean Reserve Strength

Mean Resistance

Frequency

Value

Load

Resistance

Failure Zone

scatter scatter scatter scatter
Formulation for General Case

• Reliability = Probability that Strength > Load

• Strength assessment, function of
  – Structure member sizing, load resistance path
  – Redundancy

• Load assessment, function of
  – Metocean (wind, wave, currents) conditions
  – Structure type (transparency to wind/wave)

• Uncertainties in strength & load impact reliability

• Design recipe: Ensure
  “Design” strength > “Design” load
Regional Variation on Reliability

- Blue line: Less Severe Weather (Higher Reliability)
- Red line: More Severe Weather (Lower Reliability)

Annual Probability of Structural Response Exceeding a Given Amount

Design Load

Collapse Load

Structural Response (e.g., Deck Displacement)
Summary

- Hurricane threat to offshore wind turbines exist
- Regional variation in threat across US waters
- Different structure types with different redundancies will result in varying reliability
  - Burden on designer to achieve target reliability threshold
- Design guideline recipes contain inherent target reliability
  - Recipe includes X-year wind/wave with use of safety factors
- MMI study underway on use of API and IEC recipes for extreme load reliability assessment