NATIONAL RENEWABLE ENERGY LABORATORY

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Simulating Turbulent Wind Fields for Offshore Turbines In Hurricane-Prone Regions

Yi Guo, Rick Damiani, and Walt Musial
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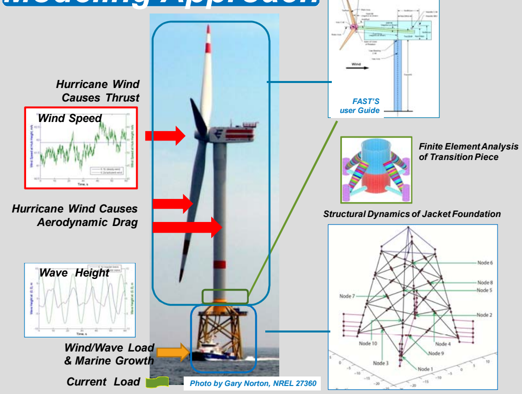
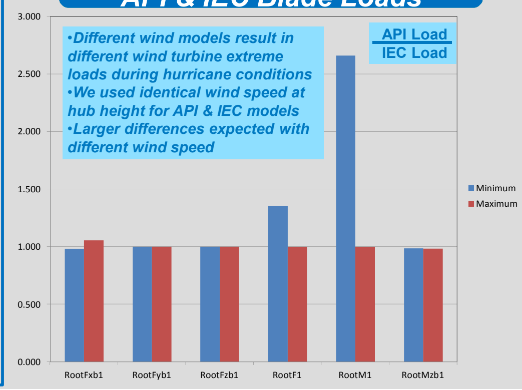
Abstract 1

Extreme wind load cases are one of the most important external conditions in the design of offshore wind turbines in hurricane-prone regions. Furthermore, in these areas, the increase in load with storm return-period is higher than in tropical regions. However, current standards have limited information on the appropriate models that can be used to simulate wind loads from hurricanes. This study investigates turbulent wind models for load analysis of offshore wind turbines subjected to hurricane conditions. Extreme wind models recommended in IEC 61400-3 and API/ABS (a widely-used standard in oil and gas industry) are investigated. The study further examines the wind turbine response subjected to hurricane wind loads. To include the API wind model, we modified TurbSim, a three-dimensional wind simulator. Finally, wind fields simulated using IEC and API wind models are used for an offshore wind turbine model established in FAST to calculate turbine loads and response.

Modeling Approach 2



Nondimensional Comparison of API & IEC Blade Loads 3



API & IEC Wind Profile Models 4

$$v(z) = v_{hub}\left(\frac{z}{z_{hub}}\right)^{0.11}, v_{hub}\text{(10-min mean)}$$

$$\sigma_I = 0.11 v_{hub}$$

IEC: wind shear model wind speed only depends on height (z)

$$v(z,t) = v(z,t_0)[1 - 0.41 I_u(z)\ln\left(\frac{t}{t_0}\right)], t < t_0$$

$t_0 = 3600$, v_0(1-hr mean at 10m above still water level)

$$v(z,t_0) = v_0[1 + C\ln(\frac{z}{10\phi})]$$

$$C = 0.0573\sqrt{1 + 0.15 v_0/\phi}$$

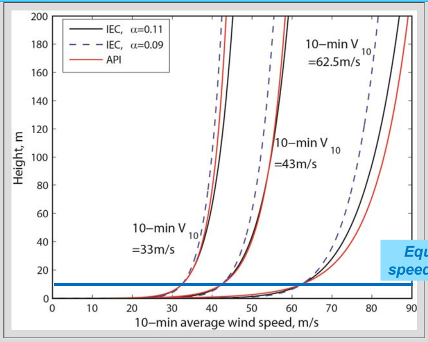
ϕ: Unit conversion

$$I_u(z) = 0.06[1 + 0.043 v_0/\phi]\left(\frac{z}{10\phi}\right)^{-0.22}$$

API: wind profile model wind speed depends on height and time (z, t)

Wind speed of the API model depends on height and time

Wind Profile: Result Comparison



API model predicts higher wind speed at heights >10m

API & IEC Wind Spectrum Models 5

$$\frac{fS_k(f)}{\sigma_k^2} = \frac{4fL_k/v_{hub}}{(1+6fL_k/v_{hub})^{5/3}}$$

k: index referring to the direction of wind speed component

L_k: integral parameter of turbulent wind speed component

IEC: Kaimal spectrum only depends on wind speed at hub height (v_{hub})

$$S(f) = \frac{320\left(\frac{U_0}{10}\right)^2\left(\frac{z}{10}\right)^{0.45}}{(1+\tilde{f}^n)^{(5/3n)}}$$

$$n = 0.458$$

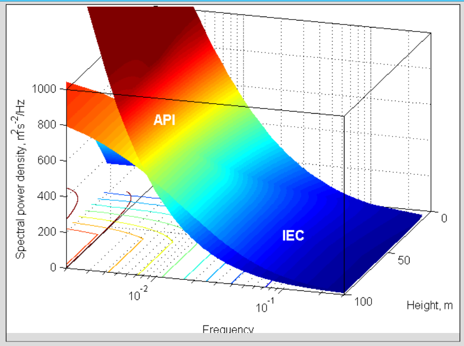
$$\tilde{f} = 172 f\left(\frac{z}{10}\right)^{2/3}\left(\frac{U_0}{10}\right)^{-0.75}$$

U_0: 1-hr mean wind speed at 10 m above mean sea level

API: Froya spectrum depends on wind speed and height (U_o, z)

API's wind spectrum is a function of hub height

Wind Spectrum: Result Comparison



API model has higher energy at low frequency <0.01 Hz

API & IEC Wind Coherence Models 6

$$Coh(r,f) = e^{\left\{-12\sqrt{(fr/v_{hub})^2 + (0.12r/L_c)^2}\right\}}$$

$L_c = \Lambda_1$, coherence scale parameter

r: magnitude of the separation vector, Normal to the average wind direction

IEC: wind coherence two-dimensional Taylor Frozen theory in longitudinal direction

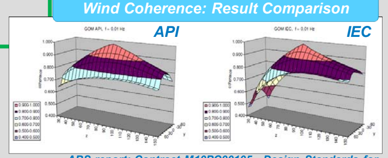
$$Coh(f) = e^{\left\{-\frac{1}{U0}\left[\sum_{i=1}^{3} A_i^2\right]^{1/2}\right\}}$$

$$A_i = \alpha_i f^{r_i} \Delta_i^{q_i} z_g^{-p_i}$$

$$z_g = \frac{\sqrt{z_1 z_2}}{10}$$

API: wind coherence, three-dimensional

Wind Coherence: Result Comparison



ABS report: Contract M10PC00105 , Design Standards for Offshore Wind Farms

API's wind coherence model is three-dimensional

Time-Averaging Intervals

$$G_{600,3600} = 1.053$$ *IEC-61400-3*

$$v(z,600) = v(z,3600)\left[1 - 0.41 I_u(z)\ln\left(\frac{600}{3600}\right)\right], t < t_0$$

$$v(z,3600) = v_0\left[1 + C\ln(\frac{z}{10\phi})\right]$$

$$I_u(z) = 0.06[1 + 0.043 v_0/\phi]\left(\frac{z}{10\phi}\right)^{-0.22}$$

API: convert wind speed between time intervals and at various heights

$$G_{600,3600} = 1.03$$ *World Meteorological Organization Gust Factor*

API converts time intervals based on wind speed and height

Conclusions

1. Different wind models result in different wind turbine extreme loads during hurricane conditions
2. The API and IEC wind models result in different wind speed extrapolation along height, wind spectrum, coherence, return-period, and time-averaging intervals
3. The API wind model has greater energy in the low-frequency range, which could excite some of the low structural modes and vibration of offshore turbines
4. The API conditions tend to generate slightly smaller load maxima, but also larger minimum values of the loads.

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