IEA Wind Task 40 Downwind Turbine Technologies

Validation of Extreme Loads of Wind Turbine by Measurement Data and Simulation

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2. Analysis method and conditions for Typhoon
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1. Background
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1-1. Background

Design

• Assume various situation WT can experience in lifetime
• Parking condition during storm wind(DLC6.1) : One of the severest

Design flow

WT spec. DLC
Safety factor

Set Design Load Cases(DLC)
WT simulation
Design loads for components

Standard > Strength

Yes
End

No

Design validation

Design validation flow

Get measurement data from prototype
Conduct simulation with condition of prototype
Compare measurement and simulation result

Prototype

Validating extreme loads of Parking condition during storm wind is very important, especially for upsizing WT
1 - 2. Objectives

(1) Validate design method by comparing simulation & measurement data during Typhoon for 5MW WT of Hitachi

(2) Study contributing factors (Eg. Turbulence intensity, wind direction change) for loads during Typhoon by simulation

(3) Estimate extreme loads for extreme wind speed by measurement data & simulation
## 1-3. Overview of 5MW WT of Hitachi

### 2 types of 5MW WT for offshore wind generation;
For regions with low and high wind speed

<table>
<thead>
<tr>
<th>Items</th>
<th>HTW5.2-136 (For low wind speed)</th>
<th>HTW5.2-127 (For high wind speed)</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>5,200kW</td>
<td>5200kW</td>
<td></td>
</tr>
<tr>
<td>Rotor diameter</td>
<td>136m</td>
<td>127m</td>
<td></td>
</tr>
<tr>
<td>Blade length</td>
<td>66.5m</td>
<td>62m</td>
<td></td>
</tr>
<tr>
<td>Annual wind speed</td>
<td>7.5m/s</td>
<td>10m/s</td>
<td></td>
</tr>
<tr>
<td>Extreme wind speed</td>
<td>55m/s (77m/s)</td>
<td>57m/s (80m/s)</td>
<td>10-mins average (3-sec average)</td>
</tr>
<tr>
<td>Wind speed Class</td>
<td>Fatigue III</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extreme S</td>
<td>T*</td>
<td>*JIS Class T</td>
</tr>
<tr>
<td>Turbulence category</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Cut-in wind speed</td>
<td>3.5m/s</td>
<td>4m/s</td>
<td></td>
</tr>
<tr>
<td>Cut-out wind speed</td>
<td>25m/s</td>
<td>25m/s</td>
<td></td>
</tr>
</tbody>
</table>

**Validation target**
1-4. Target wind turbine

- Prototype built at Kashima in Ibaraki (March, 2015)
- Measurement tower near WT for wind condition
- Replaced 127 blades to 136 blades (October, 2016)
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2 - 1. WT conditions during Typhoon 21(2017)

- Maximum averaged speed: 29.1 [m/s]
- Maximum instantaneous speed: 44.8 [m/s]

Pathway of Typhoon

*By website of Japan Meteorological Agency

Max inst.: 44.8 m/s
Max avg.: 29.1 m/s
Parked condition
Blade: Feather
Rotor slip
Active Yaw

Validation period
2-2. Analysis conditions

- Adopted actual wind & WT conditions during Typhoon

**Figure 1 Turbulent intensity**

<table>
<thead>
<tr>
<th>Items</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT model</td>
<td>HTW5.2-136 (by Hitachi)</td>
</tr>
<tr>
<td>Average wind speed</td>
<td>10～28[m/s] (2[m/s] BIN)</td>
</tr>
<tr>
<td>Turbulence intensity</td>
<td>BIN average(Figure 1)</td>
</tr>
<tr>
<td>Average yaw misalignment</td>
<td>BIN average(Figure 2)</td>
</tr>
<tr>
<td>Standard deviation of wind direction</td>
<td>BIN average(Figure 3)</td>
</tr>
<tr>
<td>Turbulence model</td>
<td>Kaimal spectrum</td>
</tr>
<tr>
<td>Turbulence seed</td>
<td>6 (Mean)</td>
</tr>
<tr>
<td>Wind shear</td>
<td>0.11</td>
</tr>
<tr>
<td>Analysis period</td>
<td>630s (Evaluation: 30～630s)</td>
</tr>
<tr>
<td>Analysis software</td>
<td>BLADED (DNV GL)</td>
</tr>
</tbody>
</table>

**Figure 2 Average yaw misalignment**

**Figure 3 Variation of Wind direction**
1. Background
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3-1. Results

・Simulation results are consistent with measurement about Loads on Blade and Tower.

Blade root (flapwise)

Comparison for max & min value in 10 minutes
Normalized by max measurement
Measurement values are calculated based on strain gauges

Tower base (Side-side)

Tower base (Fore-aft)
3 - 2. Contributing factors (1)

- Try to estimate contributing factors for loads during Typhoon by sensitivity analysis using simulation
- Conduct simulation with various parameters
- Calculate contribution rate for each parameter by multiple linear regression analysis

### Parameters & ranges

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average wind speed</td>
<td>10～28[m/s]</td>
</tr>
<tr>
<td>Turbulence intensity</td>
<td>10～24[%]</td>
</tr>
<tr>
<td>Average yaw misalignment</td>
<td>-7～7[deg]</td>
</tr>
<tr>
<td>Standard deviation of wind direction</td>
<td>7～15[deg]</td>
</tr>
</tbody>
</table>

Ranges: based on measurement data during Typhoon

![Graph: Turbulence intensity vs. Blade MY moment]

Eg. Turbulence intensity V.S. Blade MY moment

- R² = 0.9737
- R² = 0.9895

Confirmed other loads can be approximated by 2\textsuperscript{nd} order equation.
3-2. Contributing factors (2)

- Coefficient of determination ($R^2$) is more than 0.94.
  - Regression is appropriate.
- Enable to study factors for loads by comparing relative contribution rate

### Contribution rate for each parameter

<table>
<thead>
<tr>
<th>Factors</th>
<th>Blade MYS</th>
<th>Tower MXT</th>
<th>Tower MYT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed</td>
<td>58.0</td>
<td>54.3</td>
<td>54.5</td>
</tr>
<tr>
<td>Turbulence intensity</td>
<td>30.4</td>
<td>8.0</td>
<td>19.8</td>
</tr>
<tr>
<td>Variation of Wind direction</td>
<td>3.4</td>
<td>21.7</td>
<td>10.3</td>
</tr>
<tr>
<td>Yaw misalignment</td>
<td>3.6</td>
<td>0.7</td>
<td>4.2</td>
</tr>
<tr>
<td>Other (Residual error)</td>
<td>4.7</td>
<td>15.2</td>
<td>11.2</td>
</tr>
<tr>
<td>Sum</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

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- **Eg. Accuracy for regression about blade MY**

![Graph showing regression accuracy](chart.png)

- $R^2$ for Tower MXT: 0.94
- $R^2$ for Tower MYT: 0.97
3 - 3. Estimation of extreme loads

- Estimate extreme loads for parked condition with storm wind (55[m/s]) by extrapolation
- Tendency of sim. & estimation agree with each other

Blade root (flapwise)

- Tendency of sim. & estimation agreed with each other. However validation by measurement data with higher wind speed is necessary.
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Carried out validation for extreme loads during Typhoon by comparing simulation & measurement.

Conclusions are followings,

(1) Simulation method is reasonable as simulation & measurement loads are consistent.

(2) Study contributing factors for loads during Typhoon by using simulation results

(3) Showed possibility to estimate extreme loads by comparing simulation & extrapolation of measurement data