Extreme load estimation of an offshore wind turbine during power production

A. YAMAGUCHI
P. W. SARLI
T. ISHIHARA
IEC61400-1 DLC 1.1
(extreme load during power production)
- Maximum load varies with different turbulent wind field.
- Maximum load for the recurrence period of 50 years is used for design.
- Although convergence criteria is provided, resulting 50 years maximum load has large uncertainty.

- The load factor 1.35 in IEC61400-1 assumes c.o.v. of the extrapolated load is 5% (Tarp-Johansen et al., 2002).
Simplified model for support structure

- JSCE guideline for support structure of wind turbine (2010)
  - Based on Ishii and Ishihara (2010)
  - 50 years maximum value can be evaluated as: \( M_{50} = C_{ext} \times \bar{M}_{max} \)
  - Extrapolation coefficient \( (C_{ext}) \) is modelled as function of annual mean wind speed and turbulence intensity.
  - Mean of the maximum moment \( (\bar{M}_{max}) \) is based on mean thrust force and gust factor.

Based on simulation at tower base moment. Validation and the applicability to other height have to be investigated.
Objective

1. Propose a new convergence criteria for extreme load extrapolation during power production to reduce uncertainty of the estimation.

2. Investigate the applicability of simplified model for extreme load estimation to the tower.
Choshi offshore test wind turbine

From manufacturer
• Dimension of Nacelle
• Blade length, twist angle and weight
• First mode frequency of blade
• Dimension and weight of tower

From JSCE guideline
• Control algorithm
• Aerodynamic property of blade

From Measurement
• Frequency and damping of the first and second mode of the tower

The wind turbine is build on gravity foundation and treated as "onshore" wind turbine with wave loading.

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Dynamic simulation was carried out by using GH Bladed to calculate the tower moment at each height.

- Measurement are bin average of the maximum load in each 10 minutes over 4 months (2013/09 - 2013/12)
- Simulation are average of maximum of 35 different simulations.

Simulation shows good agreement with measurement.
Load extrapolation

1. Minimum of 15 simulations for each wind speed is carried out.
2. Estimate probability distribution function of maximum load by using three parameter Weibull distribution.
3. Check the convergence. 
   \[
   \frac{\bar{S}_{0.84,0.95} - \bar{S}_{0.84,0.05}}{\bar{S}_{0.84}} < 0.15
   \]
4. Calculate the probability distribution of maximum load assuming Rayleigh distribution of mean wind speed.

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New convergence criteria

A new convergence criteria based on the difference between simulated load and the load based on estimated distribution function.

$$\eta = \frac{\epsilon}{s_{ave}}; \quad \epsilon = \sqrt{\frac{\sum_{j=1}^{N} (s_{sim-j} - s_{fit-j})^2}{N}}$$

- Start from 35 simulations for each wind speed.
- If $\eta \geq 1\%$, double the number of simulation
- Converged when $\eta \leq 1\%$
Comparison of convergence criteria

Under each convergence criteria, maximum load for 50 years recurrence period was estimated.

The Uncertainty of the extrapolated load is reduced
Applicability of simplified extrapolation coefficient

By using the proposed convergence criteria, the maximum load with 50 year return period is calculated for different annual mean wind speed. Extrapolation coefficient was calculated for fore-aft tower top and fore-aft tower base moment.

\[ M_{50} = C_{ext} \times \overline{M}_{max} \]

The simplified model by Ishii and Ishihara (2010) is applicable to tower base fore-aft moment, but not to tower top.
Applicability of simplified extrapolation coefficient

\[ M_{50} = C_{ext} \times \bar{M}_{max} \]

Tower moment based on thrust force on the rotor (Ishii and Ishihara [2010])

\[ \bar{M}_{max} = G_D (M_T + M_{Tower} + M_{Nacelle}) \]

The thrust force based model is applicable to tower base but not to the tower top

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Conclusion

• A new convergence criteria was proposed for load extrapolation. The C.O.V. of the extrapolated 50-year extreme load is reduced to 5.6% from 8.9% by using the proposed criteria.

• The simplified model for 50-year extreme load based on the thrust force on the rotor is applicable to tower base but not to the tower top, because the moment on the rotor is dominate factor at the tower top.
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