Load validation using nacelle mounted lidars: progress and challenges

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Nikolay Dimitrov, Anand Natarajan, Rozenn Wagner
DTU Wind Energy

DTU

Abstract

Aeroelastic load simulations on a Siemens 2.3MW wind turbine have been validated using load measurements from the turbine and wind inflow measurements from a Nacelle based Lidar. A detailed survey of industrial usage of Nacelle mounted Lidars has also been conducted to extrapolate the findings from the present study to a broader framework. Based on this information we assess the current technology status and recommend future focus areas.

Introduction

Nacelle-mounted lidars have high potential as tools for wind turbine load validation. Some pros and cons include (see [1],[2],[3] for details):

- **Beneficial features of nacelle-mounted lidars:**
  - Scanning multiple points;
  - Always scanning directly upwind of the rotor.
- **Some technical challenges in achieving a quality load validation with nacelle-mounted lidars:**
  - Data processing is different from the one used for mast-based measurements
  - Relatively low scanning frequency
  - Cases of low availability
  - Volume-averaged measurements
  - Rotor induction
- **The most essential environmental inputs for load simulations:**
  - 10-minute average wind statistics: mean wind speed, turbulence, and wind shear – with yaw angle and veer affecting the results to a lesser extent.
  - Turbulence spectrum is of interest as it is used to define the properties of the turbulence realizations used in the simulations.

Objectives

We use information from:

- Load measurement campaign in Denmark
- Survey among lidar users in wind energy industry
- Numerical load assessment tools

To answer:

- Can we use solely lidar-based wind inputs to load simulations for load validation?
- Could we match or even improve the level of load prediction accuracy achievable with mast-based data?
- What are the areas which need focus in the future?

Methods

Load measurement campaign

- Carried out at the Nørrekær Enge (NKE) wind farm in Northern Denmark.
- A Siemens 2.3MW wind turbine equipped with load sensors.
- A ZephIR continuous-wave and an Avent 5-beam pulsed lidar [4] were mounted on the nacelle, and calibrated following the procedure defined in [4].
- A met mast at 2.5 rotor diameters distance was available as supplemental data source.

Aeroelastic load simulations

- Mean wind speed, wind shear, veer, yaw misalignment and rotor induction are reconstructed from lidar line-of-sight measurements using 10-minute mean values [3].
- The effect of volume averaging is estimated by considering the lidar as a low-pass filter, where the amount of filtering depends on the turbulence spectrum [2].
- Turbulence is estimated by adjusting the variance of the turbulence residuals for volume-averaging, induction, and beam line-of-sight angles. An alternative turbulence estimation is done using the lidar Doppler spectrum [2] – available for the continuous-wave lidar only.

Online survey

- Various wind turbine manufacturers, wind farm owners and Lidar manufacturers were requested to provide their inputs on the type of nacelle mounted lidar measurements that have been made on different wind farms and turbines.
- In all 18 respondents were surveyed.

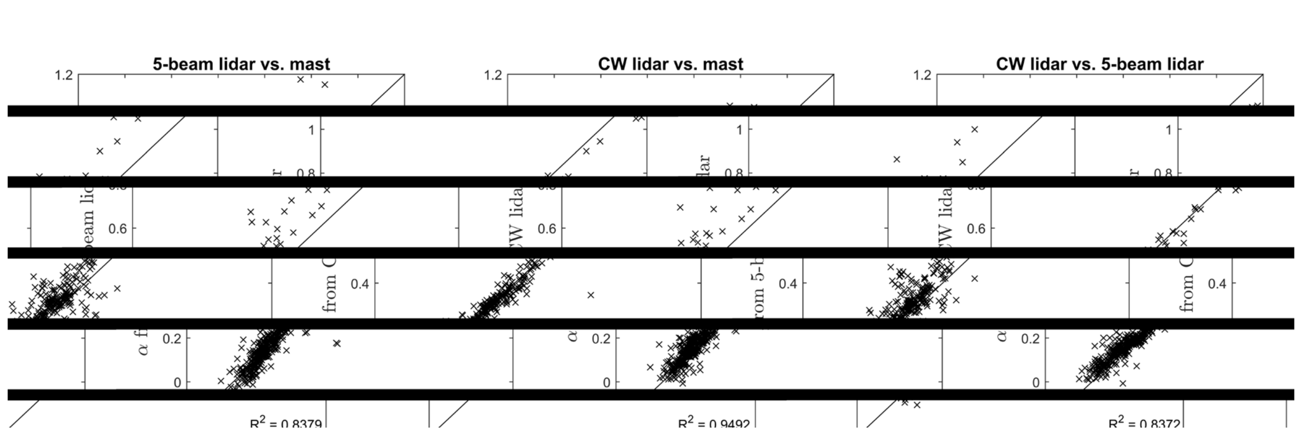

Figure 1. Recovery of wind shear from nacelle mounted lidars – comparison with wind shear estimated from mast at 2.5 rotor diameters distance.

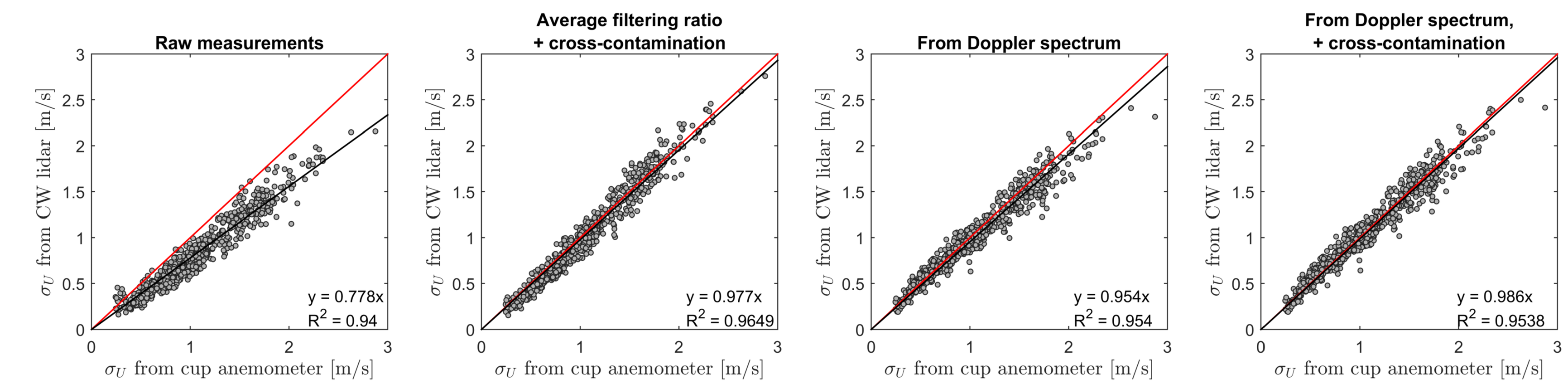

Figure 2. Recovery of wind turbulence from nacelle-mounted lidars using corrections for volume averaging and cross-contamination due to misalignment of lidar beams with main wind direction.

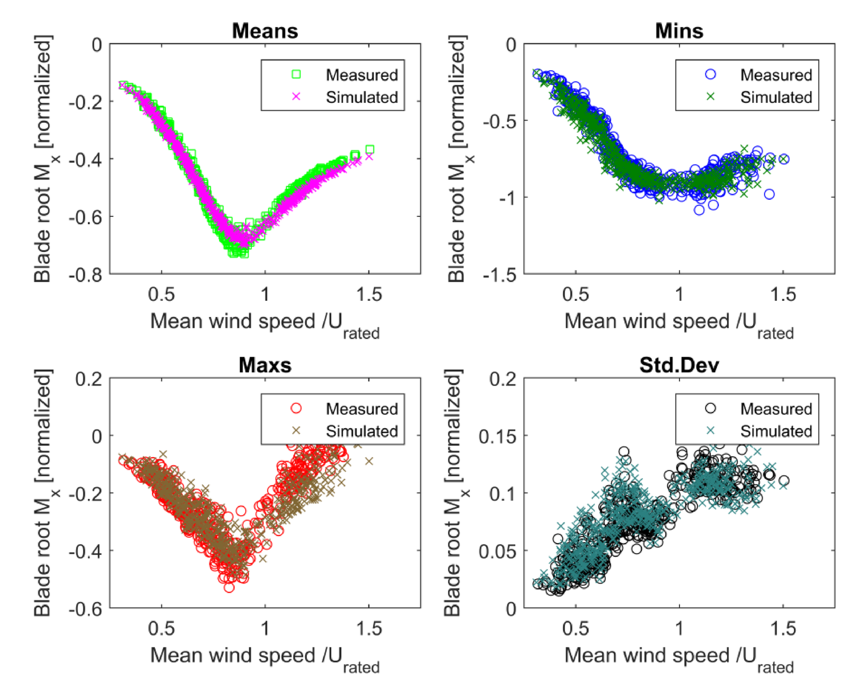

Figure 3. Comparison between measured and simulated blade root flapwise load statistics for a narrow wind direction sector (102.9° ± 5°) at Nørrekær Enge. Simulation inputs are derived using a 5-beam nacelle-mounted lidar.

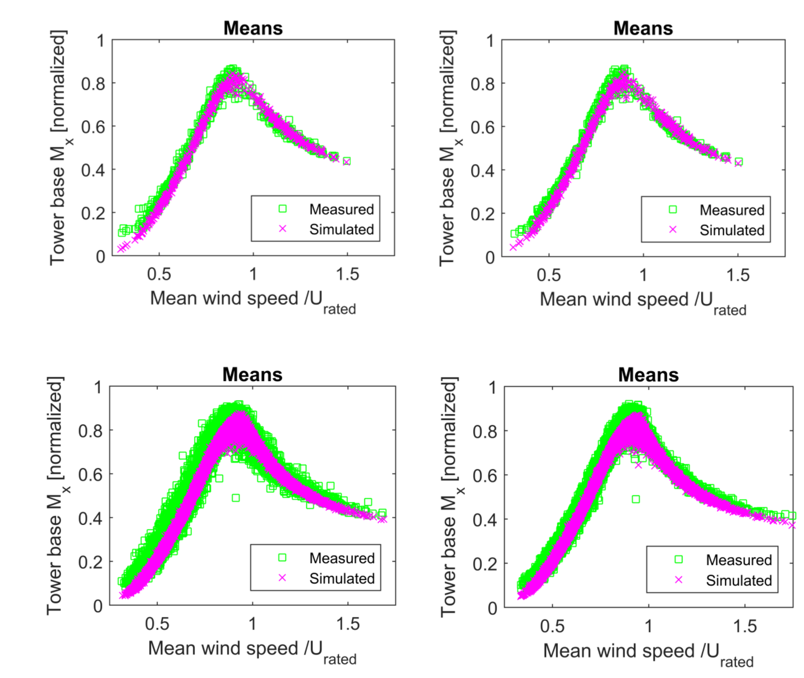

Figure 4. Comparison between measured and simulated mean tower base bending moment at Nørrekær Enge. Top left and right: comparison for narrow wind direction sector (102.9° ± 5°). Bottom left and right: comparison for wide wind direction sector (96° − 225°). Left: using statistics from mast data, right: using lidar-derived statistics.

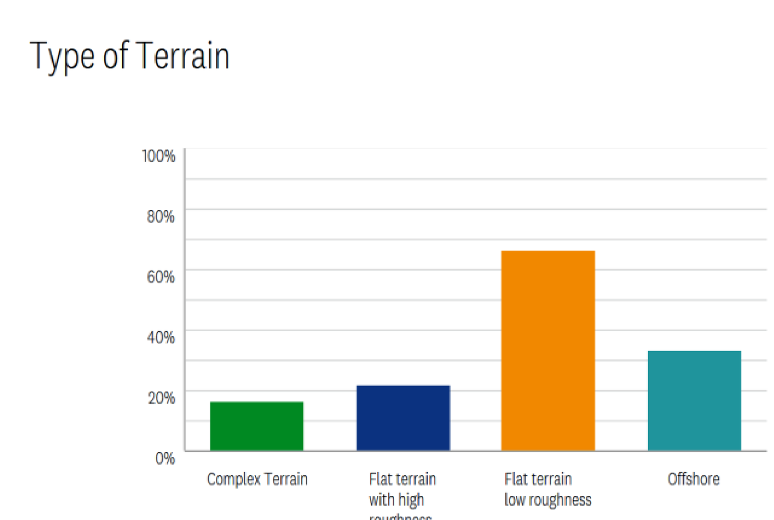

Figure 5. Survey results: variation of the usage of nacelle mounted Lidars over different wind farm terrains.

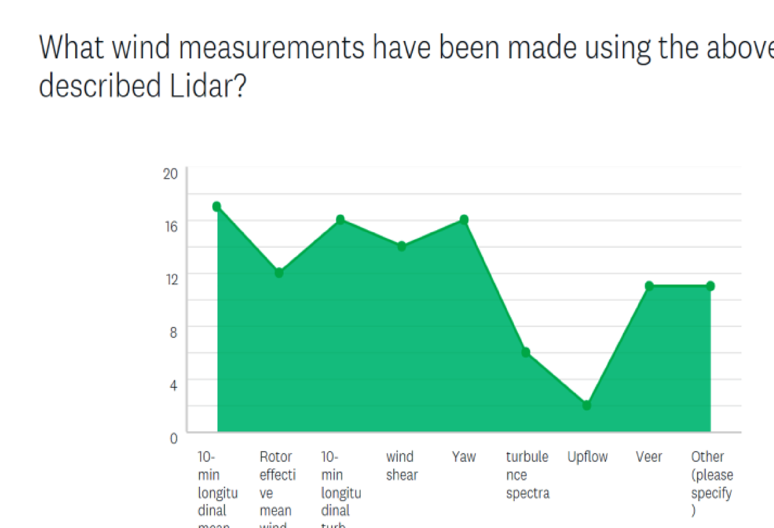

Figure 6. Survey results: type of measurements made using nacelle mounted Lidars.

Results summary

- Using lidar-based estimations of wind conditions, it was possible to reproduce the loads measured at the Nørrekær Enge site with sufficient accuracy.
- The most demanding task was to estimate turbulence as it is subject to multiple uncertainties. The Doppler spectrum method is more straightforward, but this Doppler spectrum is not always provided from measurements as it requires saving very large amounts of data.
- In general the load validation with nacelle-based lidars seems to be more accurate than mast-based load validation, because the nacelle-based lidars always measure directly upwind.
- The survey results showed that nacelle-mounted lidars are increasingly used by industry, including for load validation purposes – but mainly on flat terrain sites.

Conclusions

- Nacelle-mounted lidars using current-day technology are generally capable of providing sufficiently good input for load validation at sites with flat terrain or offshore where ambient turbulence is not a critical factor.
- In some cases nacelle-mounted lidars may perform better than masts since the lidars follow the turbine orientation and are thus constantly measuring exactly upwind of the wind turbine.
- Due to the technical hurdles imposed by the volume-averaging effect of lidars, and due to the measurements only consisting of a single line-of-sight component, obtaining second-order wind statistics such as standard deviations and spectrum is a challenge which requires additional efforts in comparison with other wind speed measurement technologies.

References

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