Full two-dimensional rotor plane inflow measurements by a spinner-integrated wind lidar

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Introduction
Wind turbine blade reduction and power performance optimization require advanced control strategies that are active in areas of the wind energy community. In particular, feed-forward control using upward inflow measurements by laser light detection and ranging (LIDAR) combined with remote sensing instruments has attracted increasing interest during the last couple of years. So far, the reported inflow measurements have been a few measurements per direction or at most on a circle in front of the turbine which is not optimal in a complex inflow such as in the wake of other turbines. In this paper, we present novel full two-dimensional radial inflow remote measurements.

The field campaign 2012
During the summer of 2012, a proof-of-concept field campaign was established. A two-dimensional upward scanning wind lidar was mounted on the rotating spinner of an operating Vestas V90 turbine (59 m hub height and 80 m rotor-diameter) located at Tønderborg Engen in western Denmark. The new two-dimensional scanning device including two rotating prisms was integrated on top of a modified Zeqhir 300 continuous-coherent Doppler lidar (ContravesZeqhir) operating at a wavelength of 1.5 μm. The lidar was modified to show deflected Doppler spectra at a rate selectable up to about 500 measurements per second. This ensured short enough transversal sampling volumes when the prisms were rotating at maximum speed.

The scanning strategy
The scanning speed is adjustable and it is possible to perform within only one second a complete two-dimensional scan pattern covering an upward spherical surface in the rotating coordinate frame of the spinner, bounded by the perimeter of a cone with its apex in the spinner-mounted lidar and with a full opening angle of 60°.

Additional measurements
Turbine parameters such as yaw direction, yaw misalignment and wind speed on top of the nacelle were logged as well as wind in the nearby met mast. Fixed-bedding moments in the blades were acquired by an optical fiber-based strain measurement system. This data will be used in a future analysis to study the correlation between the scanning wind field and the load on the turbine.

In this paper, a proof-of-concept trial with a blade-mounted lidar was performed during the measurement campaign. This is reported in a separate EWEA 2013 contribution (Abstract ID 460).

The Spinner Lidar approach
In order to achieve full two-dimensional line-of-sight inflow measurements, a special laser beam scanner has been designed at the DTU Wind Energy Department. It is based on two rotating prisms which define the laser beam direction by 15° resulting in a space filling scan pattern within a full opening angle of 50° on an upward spherical surface. The scanner is similar to the short-range WindScanner® developed at the same department. However, the SpinnerLidar implementation is only using one motor with a fixed gear ratio (7:13) between the two prism axis in order to achieve a reliable implementation for turbine control applications.

Conclusion
The study presented here is the novel full two-dimensional correlation of the previous inflow measurements on a cone presented in Ref. 1. The data set with two-dimensional upward radial wind speeds poses interesting questions concerning properties in the measured inflow to extract and how they can be used in wind turbine control algorithms. In summary, this two-dimensional laser-based turbine inflow measurement technique provides new capabilities and prospects for advanced feed-forward control of turbines in complex inflows.

References

Stable atmosphere without wake influence

Unstable atmosphere with wake influence

The inflow scanned at night on a spherical surface at a measurement distance of 100 m during periods of 10 seconds without any influence from wakes from nearby turbines. The line-of-sight speeds measured have been converted to axial (along the rotation axis of the wind turbine rotor) wind speeds corresponding to the measured projection along the line-of-sight of the lidar.

The yaw direction of the turbine, yaw misalignment and wind speed measured without wake influence during a period without wakes. The signals are down-sampled to 0.5 Hz.

The yaw direction of the turbine, yaw misalignment and wind speed measured during a period with wake influence. The signals are down-sampled to 0.5 Hz.

The time evolution of the axial wind speeds along a horizontal curve at hub height during a wake-free period in a stable atmosphere with vertical shear.

The time evolution of the axial wind speeds along a horizontal curve at hub height during a period with wind influence, i.e. at toe wakes.

The time evolution of the axial wind speeds along a horizontal curve at hub height during a wake-free period in a stable atmosphere with vertical shear.

The time evolution of the axial wind speeds along a vertical curve at the center of the turbine during a wake-free period in a stable atmosphere with vertical shear.

The time evolution of the axial wind speeds along a vertical curve at the center of the turbine during a period with wake interaction. However, the wake is not present in this particular vertical section.

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