UniTTe –Turbine performance assessment with nacelle lidars

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Introduction

UniTTe (Unified Turbine Testing) is an international research project lead by DTU Wind Energy developing a new paradigm for wind turbine power performance and loads testing, where a measuring mast is no longer needed and the same universal procedure can be used to test wind turbines in all types of terrain.

Nacelle mounted lidars have become relevant alternatives to mast mounted instrumentation, as they can be installed directly on the wind turbine and remotely measure the wind speed in front of the rotor. Nacelle lidars were shown, in a previous research project [1], to accurately measure the wind speed [2]. However, the lidar used in this project could only measure at hub height whereas the turbine power performance and loads depend not only on the hub height wind speed, but also on the variation of wind speed and direction with height (shear and veer), and on the wind speed fluctuation (turbulence intensity) [3,4]. With the most recent developments in lidar technology, with one beam scanning the wind field or several beams measuring at various positions, the measurement of these parameters is now possible with a new generation of nacelle mounted lidars, so-called profiling nacelle lidars, that are able to measure the wind profile in front of the rotor [5, 6].

In flat terrain, the wind speed measured 2 to 4 diameters upstream can fairly be assumed as identical to the wind speed that would be sensed at the turbine location if there was no turbine. In complex terrain however, this assumption fails because the flow is affected by the topography. According to the current standards this requires a 'site-calibration' ([7] Appendix C) to be carried out, in which a mast upstream and a second mast at the turbine location are used to measure the transfer function of the wind between the two locations before the turbine can be installed and the testing begin. This becomes particularly difficult and expensive as the wind turbines increase in size.

The new generation of nacelle mounted lidars can easily measure the wind field closer to the rotor and thus increase the correlation between the measured wind speed and the turbine power and loads. The inflow approaching the turbine is slowed down by the blockage effect of the spinning rotor [8], and we expect this effect to overcome the other effects influencing the wind field, so that, close to the rotor, the wind field is essentially the same for a wide variety of terrain and atmospheric conditions.

Approach

Instead of using mast mounted instruments measuring the free-stream wind speed far upstream, we propose to use modern, nacelle-mounted wind lidars, measuring the wind field a short distance ahead of the rotor. With these measurements, the correlation between the wind and the turbine response (loads and power) will be increased and the influence of the terrain on the measurements will be minimized, allowing the same procedures to be used both offshore and in mountainous terrain. UniTTe, performed by a consortium of 11 partners, covering a broad spectrum of international players in the wind industry, aims at delivering the future industrial procedures for loads and power verification that will also form the basis of new international standards.

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This paper presents the results obtained in the first phase of the UniTTe project: wind turbine performance assessment using profiling nacelle lidars measurements taken in the rotor inflow in flat terrain. Those combine fundamental research into how the flow approaching the turbine is modified by terrain types and detailed analysis of nacelle lidar measurements. The following research questions are addressed:

- How to properly model the flow as it approaches the turbine rotor?
- How can the near rotor inflow be related to the free wind field?
- What are the relevant parameters necessary to characterize the power and loads response of the turbine to the wind field?
- How well can these parameters be measured by a nacelle mounted lidar?
- What are the uncertainties inherent to the measurements performed using a nacelle mounted lidar?

Main body of abstract

First of all, a methodology for calibrating profiling nacelle lidar has been developed. The basic principle of the methodology is that the radial wind speed measured by a lidar is compared to collocated and simultaneous measurements taken with a reference cup anemometer. The parameters to be accounted for in addition to the radial wind speed are the angles between the beams and the measurement range. The various sources of uncertainty contributing to uncertainty of the wind speed measurement have been identified, quantified and their combination has thoroughly been thought through. An Avent 5 beam lidar and a ZephiR Dual Mode have been calibrated with this methodology.

In a second phase, both nacelle lidars have been installed on a Siemens 2.3MW wind turbine in the Nørrekær Enge wind farm, surrounded by flat terrain, in Denmark (see Figure 1). A met mast, compliant to the IEC 61400-12-1:2005 requirements, has been used as reference wind speed measurement. Moreover the turbine has been instrumented for a full load assessment including strain gauges on the blade roots and the top and bottom of the tower.

Figure 1 Picture of the Avent 5 beam demonstartor and the ZephIR Dual Mode lidars installed on the nacelle of a multi-megawatt wind turbine

An algorithm to derive the wind parameters (horizontal wind speed, direction, shear, veer) from the lidars radial wind speed measurements has been developed. This algorithm is based on a fit of the radial wind speeds to a wind model which can include a variable number of parameters. The reconstruction can be applied to various measurement ranges, e.g. 2.5D, or 1D upstream of the rotor, in which case the rotor induction has to be taken into account.

Computational modelling of the turbine inflow was necessary to better understand the induction. CFD simulations using an actuator disc have been validated against 3-dimensional measurements of the inflow to a 500kW turbine obtained with the Short Range WindScanner (a system based on three synchronized ZephIR lidars). Then, simulations for 4 different rotor designs ranging from 500kW to 5MW turbines showed that the mean velocity profile up to 1 rotor radius upstream is independent of the rotor design and wind speed (to within 0.6% of the free-stream). A row of wind turbine rotors with a mutual spacing of 3 diameters has been simulated RANS simulations and a simple inviscid vortex model. The simulations show that the power production of the turbines deviate significantly compared to a corresponding isolated turbine even though there is no direct wake-turbine interaction at the considered wind directions.

Finally, the reconstructed wind parameters from the nacelle lidars were used in power performance measurement and loads assessment. We demonstrated a method for incorporating wind velocity measurements from multiple-points canning lidars into three dimensional wind turbulence time series serving as input to wind turbine load simulations. Simulated lidar scanning patterns were implemented by imposing constraints on randomly generated Gaussian turbulence fields in compliance with the Mann model for neutral stability. A numerical study is made using the HAWC2 aeroelastic software whereby the constrained turbulence wind time series serves as input to load simulations on a 10MW wind turbine model, using scanning patterns simulating differentnlidar technologies. Lidar measurements as turbulence constraints in load simulations may bring significant reduction in load and energy production uncertainty.

Conclusions

We have developed and demonstrated new procedures for wind turbine power curve measurement and load assessment based on the measurement of inflow to the turbines with nacelle lidars. Those procedures were derived from experimental data obtained with two different types of nacelle lidars.

Testing without the need for a mast will have a major impact on prototype testing, contractual tests, and operational tests offshore and onshore, since it will allow performing more and considerably cheaper power and load verifications.

Ultimately the objective of the project is to form a sound scientific basis for the next generation of international standards for wind turbine power measurement and loads assessment. These standard procedures will reduce the measurement uncertainties and consequently result in cheaper wind turbine testing.

Learning objectives

- Uncertainties in nacelle lidar measurements
- Understanding of the inflow toward a turbine rotor
- Method to reconstruct the wind parameters from lidar measurement
- Application of Lidar scanning patterns to constrained Gaussian turbulence fields for load validation
- Power curve measurement and loads assessment with nacelle lidars

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