Application-oriented classification of lidar profilers - or: Introducing lidars to power performance

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Commercially available lidars have reached a level of accuracy where they can be considered as serious alternative to standard cup anemometers – especially with significant advantages in large heights or in areas where it is difficult and costly to set up a measuring mast. A further benefit is that lidars can measure wind speeds and wind directions simultaneously at different height levels, why they are particularly suited for the measurement of vertical wind shear.

A standardized application to power performance testing (as well as more generally resource assessment), however, requires a traceable classification scheme that allows for a complete evaluation of the uncertainty of the measurements performed by the lidar.

The procedure, we propose, is based on the verification of a ground-based lidar profiler against a tall meteorological mast that is equipped with reference sensors at different height levels. Following the recommendations for the evaluation of cup anemometers in IEC 61400-12-1, the verification test is analysed in terms of both a calibration and a classification of the tested instrument. In this way, traceability is transferred from the reference sensors to the tested lidar and a respective lidar uncertainty is deduced accordingly.

The work presented here has been carried out as part of the EU FP6 UpWind project (WP 6) and is directly connected to IEC MT12-1 currently revising the IEC 61400-12-1 standard for power performance testing.

In 2009, for this purpose, the Lidar Acceptance Project was initiated to organise the work on lidar testing and classification issues related to IEC standard revision in a satellite group.

### Estimation of uncertainties

#### Uncertainty budget for lidar measurements:

- reference uncertainty, i.e. combined uncertainty of cup anemometer measurements ($u_{an}$)
- lidar calibration uncertainty – defined by uncertainty of calibration function (if calibration is applied; $u_{lid cal}$)
- lidar classification uncertainty – estimated by $\sqrt{\sum c_i^2 / (N-1)}$, ($c_i$: lidar error) with respect to covered range of external conditions ($u_{lid, class}$)

\[
\begin{align*}
\text{Additional uncertainty due to mounting / setup of lidar} \\
\text{Additional uncertainty due to specific conditions during application not covered by verification test}
\end{align*}
\]

### Discussion

The presented lidar verification scheme prepares basis for:

- traceable lidar measurements (to the reference sensors)
- repeatable lidar measurements (with respect to a well defined uncertainty)
- a consistent evaluation of uncertainties (in line with IEC 61400-12-1 and GUM).

Results of the verification test are evaluated as calibration and as classification at the same time – with the drawbacks that the calibration functions depend on the specific external conditions and only a certain range of the possible conditions is covered by the classification.

The lidar calibration is based on a reference that is itself associated with a significant uncertainty. A necessary assumption is that the reference is unbiased and that the uncertainties are symmetrically distributed (cf. Ref. 2).

Lidar calibrations depend not only on the actual site conditions (eg vertical wind shear, turbulence) but also on the measurement height. Extrapolations between verification test and application are to be considered.

Some (rough) numbers from our observations:

- $u_{lid, class} \approx 0.2 \text{ m/s without calibration}$
- deviations due to varying external conditions or height extrapolations 0.01-0.02 m/s (but also extreme cases with larger deviations)
- $u_{lid, cal}$ negligible (for all three introduced models)

### References

1. IEC 2005 Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines (IEC 61400-12-1 International standard)

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