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INTERNATIONAL NETWORK OF WIND ENERGY
MEASUREMENT INSTITUTES

Procedure for Ground Based Lidar Verification

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1. Introduction

The Measnet Ground Based Lidar Verification Procedure is the measurement procedure agreed upon by the Measnet members to be mutually used and accepted. The procedure provides the basis for a common interpretation and understanding in accordance with the Measnet Quality Evaluation Program, whose main objective is the continuous improvement of the measurement quality.

The Measnet Remote Sensing Expert Group (RS ExG) has agreed to compile the present document, which provides the common understanding and implementation of the Reference Standard among the organization. The procedure includes -where required- interpretations of specific technical issues, guidance for implementation of ground based lidar verification and specific additional requirements such as a methodology for quantifying the Proficiency Test results.

The document will also be utilized in the assessment of Measnet applicants.

2. Reference Measurement Procedure

The Reference Measurement Procedure on which the current Measnet Ground Based Lidar Verification Procedure is founded is:

IEC 61400-50-2, Edition 1, 2022: Wind energy generation systems- Part 50-2: Wind measurement– Application of ground-mounted remote sensing technology (Chapter 7–Verification of the performance of RSDs and Chapter 8 – Evaluation of uncertainty of measurement by RSDs).

2.1. Verification of the performance of RSDs

The following requirements shall be assessed through suitable tests and the results shall be considered if necessary. The RS ExG has provided the following recommendations:

- 1) About the measurement data, there should be no rounding before calculation.
- 2) The reference meteorological mast and the lidar measurements shall be free of wakes from wind turbines and obstacles as defined in clause 6.3 points (a) and (b) in [2].

It should be noted that this applies to all probe volumes (each measurement position along the lidar beam, i.e. a lidar with four beams showed in Figure 1). The probe volume coordinates are defined at the center point of the probe volume to evaluate possible wakes effect. This is considered to be a reasonable simplification. The position of the probe volumes is given by the direction of the beams, the cone angle and the considered measurement height.

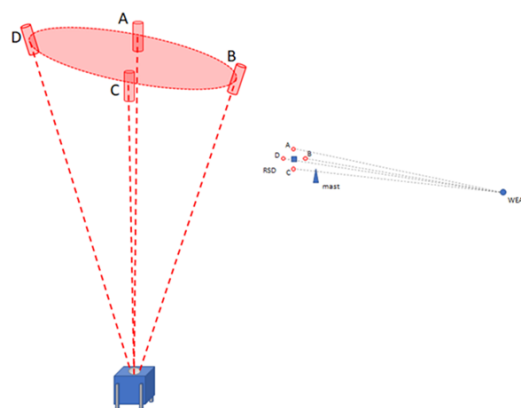


Figure 1. Lidar with four beams

- 3) The wind speed range (average value of reference wind speed) is 3.75m/s–16.25m/s (lower boundary included, upper boundary excluded.)
- 4) The RSD availability for data filtering should be determined based on the lidar classification report or according to the recommendations from lidar manufacturers.
- 5) The reference anemometer should have at least 99% availability in each 10-minute period.
- 6) All reference and RSD data must satisfy the conditions that $\text{std} > 0$ and $\text{min} < \text{mean} < \text{max}$.
- 7) The reference wind speed should be used as the independent variable for wind speed binning.
- 8) The RSD wind speed should be used as the independent variable of the regression of the calibration function.

2.2. Evaluation of uncertainty of measurement by RSDs

Regarding the type B uncertainty, the recommendations from the RS ExG are as follows:

- 1) The wind tunnel reference uncertainty on the calibration certificate is converted to one standard deviation (i.e., if the uncertainty is given in $k=2$, it is divided by 2 to obtain $k=1$). Then it is interpolated linearly to the bin-wise mean wind speeds (obtained in the RSD verification analysis), using constant extrapolation if required.

The anemometer calibration uncertainty is obtained by adding in quadrature:

- The interpolated wind tunnel reference uncertainty, converted to $k=1$, the interpolated residuals (deviation between reference and anemometer output) and the post-calibration uncertainty.

If the anemometer passes the in-situ test ($\delta < 0.1$ m/s) or post-calibration, i.e. after being used as the reference sensor for the RSD verification, the post-calibration uncertainty contribution can be set to 0% (per IEC 61400-50-1:2022, clause 11.3.3, page 58.)

- 2) The RS ExG proposes the following regarding the verification of uncertainty contributions.

- For mounting effects, $u_{VR,mnt,i}$, the default magnitude of 0.1% (IEC 61400-12-1:2022, clause E.7.5) can be used, provided the RSD is correctly installed on a solid stable base.
- For non-homogeneous flow 0% can be used, if the RSD is used in flat terrain. The definition of flat terrain should follow the IEC 61400 12-5:2022, clause 9.

Furthermore, it could be clarified that clause 8.7 of IEC 61400-50-2:2022 is used during the application of the RSD. (During verification, only the contributions in clause 8.3 apply.) Hence, the classification uncertainty contribution, $u_{VR,class,i}$, is not used during the verification of the RSD.

Annex A

Measnet Ground Based Lidar Verification Proficiency Test Rules

*Note: For Proficiency Tests organized by Measnet in collaboration with IECRE, the IECRE Operational Document takes priority over the following items.

1.1. Responsibilities

The Measnet Proficiency Test (PT) on Ground Based Lidar Verification is organized under the responsibility of the Measnet Remote Sensing Expert Group (RS ExG), who nominates the conductor for each PT.

1.2. PT plan

A PT plan should be agreed upon and shall be documented before commencement of the scheme, and should include the following information:

- a) The name and address of the PT provider;
- b) The name and address of the conductor and other personnel involved in the design and operation of the scheme;
- c) The nature and purpose of the scheme;
- d) The reference procedures;
- e) The expected participants (names and addresses).

Additionally to the above, the PT plan should include information on the following:

- a) Description of measurement layout including information on the Lidar and the reference instrumentation;
- b) Timeseries of the Lidar measurements during the verification period at two heights;
- c) Timeseries of the reference instruments measurements during the verification period.

1.3. Statistical analysis of PT results

The following steps need to be followed, and the following results need to be provided:

1. Definition of the valid measurement sector according to clause 6.3 points (a) and (b) of [2];
2. Statistics of the valid datapoints (10 min average values):
 - a) Number of valid datapoints;
 - b) Mean difference of the lidar from the reference expressed in m/s;
 - c) Standard deviation of the difference of the Lidar from the reference expressed in m/s;
 - d) Coefficients (slope, m , offset, b , and coefficient of determination R^2) of the linear regression analysis.
3. Bin statistics based on 0.5m/s wide bin intervals of average value of reference wind speed in the range from 3.75m/s to 16.25m/s.
 - a) Bin average value of reference wind speed;
 - b) Number of datapoints, average, minimum, maximum, standard deviation of RSD wind speed;
 - c) Bin average value of the difference of the lidar from the reference expressed as percentual value.
4. Uncertainty for each wind speed bin expressed as percentual
 - a) Type B uncertainty of reference wind speed;
 - b) Type B uncertainty of RSD wind speed;
 - c) Total standard uncertainty (coverage factor $k=1$) of the verification (IEC 61400-50-2:2022, clause 8.3);
 - d) Total standard uncertainty (coverage factor $k=1$) of the lidar measurements(IEC 61400-50-2:2022, clause 8.1).
5. Verification function to corrected RSD wind speed= $\mathbf{m}_{cor} \times$ RSD wind speed+ \mathbf{b}_{cor}
 - a) Slope, \mathbf{m}_{cor}
 - b) Offset, \mathbf{b}_{cor}

Annex B

Compatibility Index E

Compatibility index E measures the ratio between the deviation of the measurements of the laboratory and the declared uncertainty. It is defined as:

$$E = \frac{|V_L - V_{PT}|}{\sqrt{U_L^2 + U_{PT}^2}}$$

where V_L is the result according to the laboratory calibration, V_{PT} is the proficiency test reference result and U_L and U_{PT} are the expanded uncertainties ($k=2$) of the laboratory's measurement and of the proficiency test reference result, respectively (see equation B.5 of ISO/IEC 17043, Ed.2 (2023)). The test reference result uncertainty is estimated as:

$$U_{PT} = \frac{\sigma}{\sqrt{N}}$$

where σ is the standard deviation of the results declared by the laboratories and N is the number of laboratories that have been used to calculate the proficiency test reference results.

The compatibility index E, which is based on the participants' reported estimates of measurement uncertainty, are only meaningful if the uncertainty estimates are determined in a consistent manner by all participants. This requirement is fulfilled in the present application.

A compatibility index bigger than 1 indicates that the deviation of the laboratory from the PT reference value is not compliant with the laboratory's declared uncertainty.

*Note : The Compatibility index E can be calculated for each wind speed bin, and in order to simplify, it is recommended to take the bin with average wind speed 12m/s or any specified bin as an example to calculate the compatibility index E.

References

- [1] ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories, edition 3.0, 2017-11.
- [2] IEC 61400-50-2, Wind energy generation systems, Part 50-2: Wind measurement – Application of ground mounted remote sensing technology, edition 1.0, 2022-08.
- [3] IEC 61400-50-1, Wind energy generation systems, Part 50-2: Wind measurements – Application of meteorological mast, nacelle and spinner mounted instruments, edition 1.0, 2022-11.
- [4] ISO/IEC 17043, Conformity assessment - General requirements for the competence of proficiency testing providers, edition 2.0, 2023-5.