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**Wind energy generation systems –
Part 12-3: Power performance – Measurement based site calibration**

**Systèmes de génération d'énergie éolienne –
Partie 12-3: Performance de puissance – Étalonnage du site fondé sur le
mesurage**



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INTERNATIONAL
ELECTROTECHNICAL
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INTERNATIONALE

ICS 27.180

ISBN 978-2-8322-5596-4

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WIND ENERGY GENERATION SYSTEMS –**Part 12-3: Power performance –
Measurement based site calibration**

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IEC 61400-12-3 has been prepared by IEC technical committee 88: Wind energy generation systems. It is an International Standard.

This first edition of IEC 61400-12-3 is part of a structural revision that cancels and replaces the performance standards IEC 61400-12-1:2017 and IEC 61400-12-2:2013. The structural revision contains no technical changes with respect to IEC 61400-12-1:2017 and IEC 61400-12-2:2013, but the parts that relate to wind measurements, measurement of site calibration and assessment of obstacle and terrain have been extracted into separate standards.

The purpose of the re-structure was to allow the future management and revision of the power performance standards to be carried out more efficiently in terms of time and cost and to provide a more logical division of the wind measurement requirements into a series of separate standards which could be referred to by other use case standards in the IEC 61400 series and subsequently maintained and developed by appropriate experts.

The text of this International Standard is based on the following documents:

Draft	Report on voting
88/824/CDV	88/869/RVC

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 61400 series, published under the general title *Wind energy generation systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
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- amended.

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INTRODUCTION

The purpose of this part of IEC 61400 is to provide a uniform methodology that will ensure consistency, accuracy and reproducibility in the measurement and analysis of a site calibration for use in the determination of the power performance of wind turbines. This document has been prepared with the anticipation that it would be applied by:

- a) a wind turbine manufacturer striving to meet well-defined power performance requirements and/or a possible declaration system;
- b) a wind turbine purchaser in specifying such performance requirements;
- c) a wind turbine operator who may be required to verify that stated, or required, power performance specifications are met for new or refurbished units;
- d) a wind turbine planner or regulator who will need to be able to accurately and fairly define power performance characteristics of wind turbines in response to regulations or permit requirements for new or modified installations.

This document provides guidance in the measurement, analysis, and reporting of the site calibration for subsequent use in power performance testing for wind turbines. This document will benefit those parties involved in the manufacture, installation planning and permitting, operation, utilization, and regulation of wind turbines. The technically accurate measurement and analysis techniques recommended in this document should be applied by all parties to ensure that continuing development and operation of wind turbines is carried out in an atmosphere of consistent and accurate communication relative to wind turbine performance. This document presents measurement and reporting procedures expected to provide accurate results that can be replicated by others. Meanwhile, a user of this document should be aware of differences that arise from large variations in wind shear and turbulence. Therefore, a user should consider the influence of these differences and the data selection criteria in relation to the purpose of the test before contracting the power performance measurements.

The committee recognizes that the restructuring of the IEC 61400-12 series represents a significant increase in complexity and perhaps greater difficulty to implement. However, it represents the committee's best attempt to address issues introduced by larger wind turbines operating in significant wind shear and complex terrain. The committee recommends that the new techniques introduced be validated immediately by test laboratories through inter-lab proficiency testing. The committee recommends a Maintenance Cycle Report be written within three years of the publication of this document which includes recommendations, clarifications and simplifications that will improve the practical implementation of this document. If necessary a revision should be proposed at the same time to incorporate these recommendations, clarifications and simplifications.

WIND ENERGY GENERATION SYSTEMS –

Part 12-3: Power performance – Measurement based site calibration

1 Scope

This part of IEC 61400 specifies a measurement and analysis procedure for deriving the wind speed correction due to terrain effects and applies to the performance testing of wind turbines of all types and sizes connected to the electrical power network as described in IEC 61400-12-1. The procedure applies to the performance evaluation of specific wind turbines at specific locations.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61400-12-1, *Wind energy generation systems – Part 12-1: Power performance measurements of electricity producing wind turbines*

IEC 61400-12-5, *Wind energy generation systems – Part 12-5: Power performance – Assessment of obstacles and terrain*

IEC 61400-50-1, *Wind energy generation systems – Part 50-1: Wind measurement – Application of meteorological mast, nacelle and spinner mounted instruments*

ISO/IEC GUIDE 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement* (GUM:1995)

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

accuracy

closeness of the agreement between the result of a measurement and a true value of the measurand

3.2

atmospheric stability

measure of tendency of the wind to encourage or suppress vertical mixing

Note 1 to entry: Stable atmosphere is characterized by a high temperature gradient with altitude, high wind shear, possible wind veer and low turbulence relative to unstable conditions. A neutral and unstable atmosphere generally results in lower temperature gradients and low wind shear.

3.3

complex terrain

terrain surrounding the test site that features significant variations in topography and terrain obstacles that may cause flow distortion

Note 1 to entry: For the assessment of obstacles and terrain, see IEC 61400-12-5.

3.4

data set

collection of data sampled over a continuous period

3.5

distance constant

indication of the response time of an anemometer, defined as the length of air that shall pass through the instrument for it to indicate 63 % of the final value for a step input in wind speed

3.6

flow distortion

change in air flow caused by obstacles, topographical variations, or other wind turbines that results in the wind speed at the measurement location to be different from the wind speed at the wind turbine location

3.7

hub height

<wind turbine> height of the centre of the swept area of the wind turbine rotor above the ground at the tower

Note 1 to entry: For a vertical axis wind turbine the hub height is defined as the height of the centroid of the swept area of the rotor above the ground at the tower.

3.8

measured power curve

table and graph that represent the measured, corrected and normalized net power output of a wind turbine as a function of measured wind speed, measured under a well-defined measurement procedure

3.9

measurement sector

sector of wind directions from which data are selected for the measured power curve

Note 1 to entry: See IEC 61400-12-5 for determination of measurement sector.

3.10

method of bins

data reduction procedure that groups test data for a certain parameter into intervals (bins)

Note 1 to entry: For each bin, the number of data sets or samples and their sum are recorded, and the average parameter value within each bin is calculated.

3.11

power performance

measure of the capability of a wind turbine to produce electric power and energy

3.12

rotor equivalent wind speed

wind speed corresponding to the kinetic energy flux through the swept rotor area when accounting for the variation of the wind speed with height

3.13

standard uncertainty

uncertainty of the result of a measurement expressed as a standard deviation

3.14

test site

location of the wind turbine under test and its surroundings

3.15

uncertainty in measurement

parameter, associated with the result of a measurement, which characterizes the dispersion of the values that could reasonably be attributed to the measurand

3.16

wind measurement equipment

meteorological mast or remote sensing device

3.17

wind shear

change of wind speed with height across the wind turbine rotor

3.18

wind shear exponent

exponent α of the power law defining the variation of wind speed with height

Note 1 to entry: This parameter is used as a measure of the magnitude of wind shear for site calibration and may be otherwise useful. The power law equation is

$$v_{zi} = v_h \left(\frac{z_i}{H} \right)^\alpha \quad (1)$$

where

v_h is the hub height wind speed;

H is the hub height (m);

v_{zi} is the wind speed at height z_i ;

α is the wind shear exponent.

3.19

wind veer

change of wind direction with height across the wind turbine rotor

4 Symbols, units and abbreviated terms

Symbol or abbreviated term	Description	Unit
BinSize	bin size of wind direction bin	
$d_{j,k}$	residual in the j -th 10 min period of fold k	[W]
$d_{std,k}$	standard deviation of site calibration residuals in fold k	[W]
$\bar{d}_k$	mean value of the residuals in fold k	[W]
$F(WD, \alpha)$	site calibration flow correction determined in 9.2	
f	number of degrees of freedom of the site calibration	
H	hub height of wind turbine	[m]
k	folds in k -fold cross validation	

Symbol or abbreviated term	Description	Unit
L	distance between the wind turbine and the wind measurement equipment	[m]
N_k	number of data sets in fold k	
R	Rotor radius	[m]
Residual	site calibration residual	[m/s]
RSD	remote sensing device	
r	correlation coefficient	
s_{VT}	category A standard uncertainty of site calibration	[m/s]
$s_{VT,i}$	category A standard uncertainty of site calibration in bin i	[m/s]
$s_{VT,k}$	category A standard uncertainty of site calibration of fold k site calibration consistency parameter for wind direction bin j	[m/s]
$sccp_{j,j-1}$	site calibration consistency parameter for wind direction bin j using the site calibration correction in bin $j-1$	[°]
$sccp_{j,j+1}$	site calibration consistency parameter for wind direction bin j using the site calibration correction in bin $j+1$	[°]
s_{VT}	category A standard uncertainty of the site calibration	
$u_{dVT,i}$	category B standard uncertainty for data acquisition	[m/s]
$u_{dVT,i,j}$	uncertainty related to the data acquisition of the wind speed signal	
$u_{VT,class,i}$	category B standard uncertainty for anemometer operational characteristics	[m/s]
$u_{VT,class,i,j}$	uncertainty related to the classification of the sensors	
$u_{VT,coc,i,j}$	category B standard uncertainty for change in correction to wind direction bin j	[°]
$u_{VT,i,j}$	uncertainty from the site calibration	
$u_{VT,lgt,i}$	uncertainty related to the lightning finial	[m/s]
$u_{VT,mnt,i}$	category B standard uncertainty for anemometer mounting effects	[m/s]
$u_{VT,mnt,i,j}$	uncertainty related to the mounting of the sensors	
$u_{VT,precal,i}$	category B standard uncertainty for anemometer calibration	[m/s]
$u_{VT,precal,i,j}$	uncertainty related to the calibration of the anemometers	
$u_{VT,postcal,i,j}$	uncertainty related to the post calibration or in-situ calibration of the anemometers	
$u_{VT,rmv,i,j}$	category B standard uncertainty for removal of wind direction sensor between site calibration and power performance test	[°]
$u_{VT,sv,i}$	uncertainty component related to seasonal variation	
$u_{VT,sv,i,j}$	uncertainty related to the seasonal variation between site calibration and power performance test	
$u_{W,i}$	category B standard uncertainty for the wind direction sensor	[°]
V_{PM}	reference meteorological mast wind speed	[m/s]
$V_{Turb_measured}$	measured wind turbine location wind speed	[m/s]
$V_{Turb_predicted}$	predicted wind turbine location wind speed	[m/s]
v_h	hub height wind speed	[m/s]
v_{zi}	wind speed at height z_i	
WD	wind direction bin	[°]
WME	wind measurement equipment	
α	wind shear exponent from power law	

5 General

Generally, the wind speed measured upwind of a wind turbine can be assumed to be the same as that at the turbine location if the turbine were not there. This assumption does not hold when terrain effects are present. Furthermore, atmospheric conditions may also introduce wind speed effects. For a power performance measurement carried out according to IEC 61400-12-1, the wind speed is measured at a reference location 2 to 4 rotor diameters from the turbine under test whereas the wind speed actually required is that which would be experienced at the turbine location were the turbine not there. In complex terrain, the wind speed at the reference and turbine locations can be somewhat different due to the influence of the terrain. Therefore, a site calibration quantifies and potentially reduces the effects of terrain on the wind speed measurement. Terrain may cause a systematic difference in wind speed measurement between the position on the reference meteorological mast where an anemometer is mounted and another anemometer mounted at the equivalent height above ground at the centre of the wind turbine rotor at the turbine position. In addition, the relationship between the reference meteorological mast wind speed and the wind speed at the turbine position may also be affected by changes in atmospheric stability and/or the shear profile. Wind shear, which is the change in wind speed with height above the ground, may also be an influential parameter on this relationship as different shear profiles may cause a different relationship between the measurement points, especially if the turbine and meteorological mast are at different elevations.

Seasonal considerations: atmospheric stability, turbulence and wind shear can be related to different seasonal conditions. There are also concerns as to the effects of changes in roughness due to changes in the vegetation in the testing area or other roughness changes directly caused by different seasonal surface characteristics (water/land vs. ice/land, snow, crops, etc.). In light of these considerations, the site calibration and power curve measurement should be conducted during the same season or seasons. If the measurements are conducted in different seasons, additional uncertainty shall be applied as discussed in 11.4.

The outputs of the site calibration are:

- a) a table of flow corrections for all wind directions within the measurement sector(s) as defined in IEC 61400-12-1 and
- b) an estimate of the standard uncertainty of these flow corrections which shall be determined in accordance with the principles of ISO/IEC Guide 98-3:2008.

There are two distinct methods in which the site calibration may be evaluated. Only one method is required and the method is chosen by evaluating the data to assess shear as discussed in 9.2. The output for each method is:

- Subclause 9.3, Site calibration with shear influence: The flow corrections consist of a matrix of wind direction bins and wind shear bins where a single wind speed ratio correction factor is calculated for each point in the matrix.
- Subclause 9.4, Site calibration where shear is not a significant influence: The flow corrections consist of a slope and an intercept value for each wind direction bin. The coefficient of determination, r^2 , value for the regression shall also be reported.

This procedure is given for the wind speed defined as the hub height wind speed. This is so that the procedure does not mandate upper tip height meteorological masts, which are expensive and may be impractical, as it is possible that remote sensing devices will not be suitable for measurements in complex terrain. However, where a power curve is to be derived for the REWS definition of wind speed, then the procedure is repeated for each pair of measurement heights rather than just for the hub height.

A key element of power performance testing is the measurement of wind speed. This document requires the use of cup or sonic anemometers or remote sensing devices (RSD) in conjunction with anemometers to measure wind. Even though suitable procedures for calibration/validation and classification are adhered to, the nature of the measurement principle of these devices may potentially cause them to perform differently. These instruments are robust and have been regarded as suitable for this kind of test with the limitation of some of them to certain classes of terrain.

6 Overview of the procedure

Prior to the installation of the wind turbine (or after the removal of it if already existing) two meteorological masts shall be erected. One meteorological mast is the reference meteorological mast, which is also used for the power performance test. The second meteorological mast is a meteorological mast at the wind turbine position.

This procedure intends to characterise the correlation of the wind speeds between the two positions. Further recommendations for the selection of these positions are provided in 7.1.

The flowchart in Figure 1 provides a general overview of the preparation and analysis process.

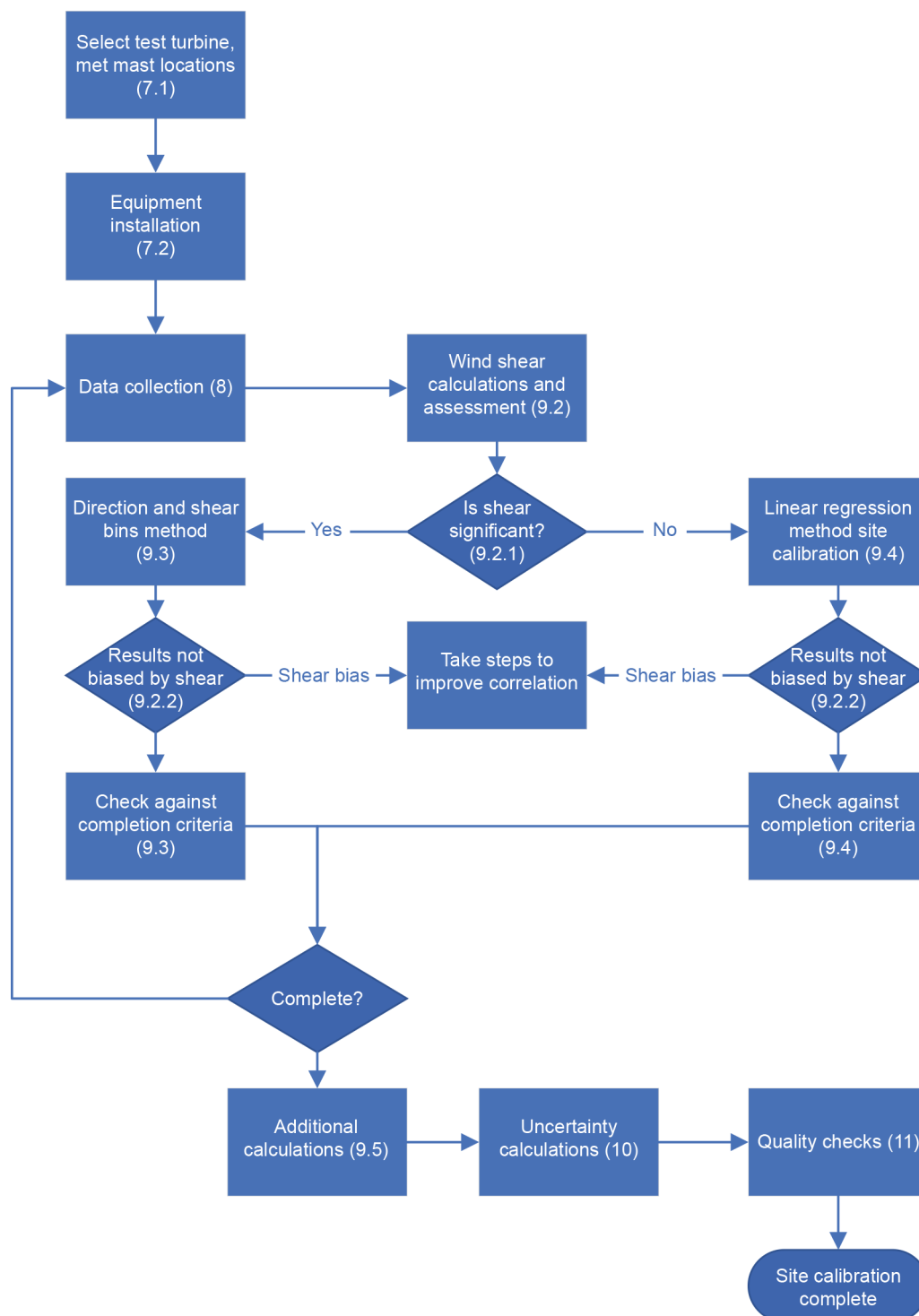


Figure 1 – Site calibration flow chart

7 Test set-up

7.1 Considerations for selection of the test wind turbine and location of the meteorological mast

7.1.1 General

The reference meteorological mast shall be the same meteorological mast that is used for the power curve measurement. The wind turbine meteorological mast shall be located as close as possible to the position where the test wind turbine will be or was located and shall be no more than $0,2 H$ from the centreline of the wind turbine where H is the wind turbine hub height. It is recommended that the wind turbine and reference meteorological masts be of the same type and have the same boom geometry so as to have similar mounting effects on the wind measurement equipment (WME).

There are a number of factors that can affect site calibration. The most notable of these are terrain, meteorological mast location, and atmospheric conditions including wind shear, turbulence and stability. These factors can vary significantly from one location to another but are often correlated with each other.

The test wind turbine location should be selected to optimise valid data collection and provide a good correlation between the reference and wind turbine meteorological masts. The purpose of site calibration is to measure the change in the boundary layer as the wind follows the orography of the terrain, which is generally attached flow, whereas obstacles have more turbulent wakes associated with them, which are affected by sharp edges and vertical surfaces that may trigger flow separation. Additionally, certain terrain features such as cliffs or steep hills may also cause the flow to separate, resulting in a poor correlation. As a guide, the terrain type should be taken into consideration when selecting the test wind turbine and the reference meteorological mast location. The terrain types discussed in this document are informative, qualitative descriptions to aid selection of the test wind turbine and reference meteorological mast locations and to provide insight on what to expect when conducting measurements in these terrain types. Examples of these terrain types are illustrated in Figure 2.

7.1.2 Type A:

Type A terrain is the least complex terrain type. Type A terrain typically does not have significant changes in elevation relative to the hub height of the wind turbine or particularly steep slopes over long distances. Examples of Type A terrain include terrain that meets the requirements of IEC 61400-12-5, gentle rolling hills, and possibly wind turbines located on a ridge facing a plain.

When conducting site calibrations at Type A sites, the wind shear conditions at the reference meteorological mast can be different from the wind shear conditions at the wind turbine location. If this is the case, then the site calibration results will likely be dependent on wind shear and wind direction.

7.1.3 Type B:

Type B terrain is moderate to complex terrain. Type B terrain includes mountains, ridgelines, large hills, and hilly sites with moderate to steeply sloping terrain and significant changes in elevation relative to the hub height of the wind turbine. Typically, the wind shear at Type B sites is low and relatively consistent, though at times negative wind shear may occur. Thus, wind shear is not expected to be as significant a factor as for Type A sites. However, at Type B sites the site calibration results often depend on both wind speed and wind direction, especially if the difference in elevation between the reference meteorological mast and the test wind turbine is more than 10 m. Thus, a linear regression correction is often appropriate for a Type B site.

The upflow/vertical wind speed component induced by the terrain at Type B sites can have a significant impact on the uncertainty, depending on the response of the anemometers to upflow. A vertical wind speed measurement may be used to assess the upflow angle, which can then be used in conjunction with the anemometer classification report to calculate an S-type

anemometer operational characteristic with user-defined influence parameter ranges as defined in IEC 61400-50-1.

7.1.4 Type C:

Type C terrain includes the most extreme terrain from a measurement perspective. Type C sites typically have a steep terrain feature such as a mountain or canyon that may cause flow separation directly upwind of the test wind turbine and create a recirculation zone at the test wind turbine location. The scale of the flow separation is defined by the terrain feature and may disrupt the wind speed correlation between the test wind turbine and reference meteorological mast even if the terrain feature is located farther than $16L$ away from the test wind turbine. L is the distance between the wind turbine and the wind measurement equipment. Type C terrain is typically so complex that the correlation between the winds at the reference meteorological mast and the test wind turbine may be poor. The flow corrections may differ significantly between adjacent wind direction bins. The data from test wind turbines at Type C terrain locations will typically have very high scatter and high uncertainty in the result.

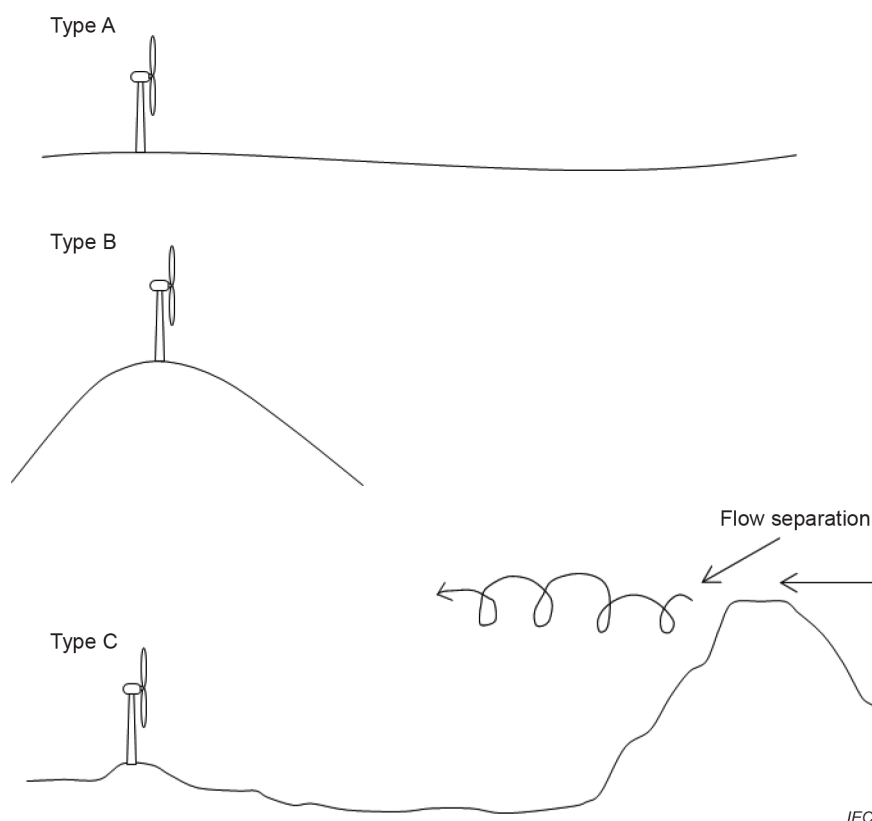


Figure 2 – Terrain types

In order to improve the correlation, the reference meteorological mast should be located such that it has a similar elevation and wind conditions as those of the test wind turbine. For example, if the test wind turbine is located on a ridge, then the reference meteorological mast is recommended to be located on the ridge next to the wind turbine instead of at a lower elevation in front of the wind turbine.

7.2 Instrumentation

The test set-up requires as a minimum measurements of hub height wind speed, wind direction near hub height, and wind shear at both meteorological masts.

WME used in the site calibration shall meet the instrumentation requirements and mounting guidelines of IEC 61400-50-1. The anemometers shall be of the same type with the same

operating characteristics and shall be calibrated in the same wind tunnel. The anemometers shall be of the same type with the same operating characteristics for the power curve measurement as for site calibration.

Depending on the site characteristics, additional measurements are recommended to provide more information about the site conditions and thus are not normative. These measurements may also be used to improve the overall quality of the site calibration and power curve measurement by identifying unusual atmospheric conditions that correlate with outliers or may be used to determine the right instrument classification and, in conjunction with the relevant classification report, quantify the site-specific anemometer operational characteristic standard uncertainty:

- a) A vertical wind speed measurement (e.g. using a 3D ultrasonic anemometer) is recommended to be carried out within 10 % of hub height or within 5 m of hub height for smaller wind turbines so as not to violate the mounting guidelines for top mounted sensors. This measurement may be used to determine the correct class for the instrument classification and, in conjunction with the instrument classification report, to quantify the uncertainty due to operational characteristics.
- b) A wind veer measurement is recommended with the lower wind direction measured within 10 m of the lower tip height wind speed measurement.
- c) If icing conditions are expected during the site calibration campaign, a temperature sensor or other means for icing detection is recommended near hub height.

Furthermore, to avoid the introduction of bias in the wind direction measurement due to uncertainty of the wind direction sensor installation, the reference meteorological mast and its wind direction sensor(s) should not be removed between the site calibration and the power curve measurement. If the primary wind direction sensor is removed or replaced, an additional uncertainty component shall be included (see 11.3.2). If the reference meteorological mast is removed and re-installed between the site calibration and the power curve measurement, the instruments shall be mounted in the same configuration and with the same boom angles during both periods so as to have similar mounting effects.

8 Data acquisition and rejection criteria

Data shall be collected continuously at the same sampling rate as for the power performance test. Data sets shall be based on 10 min periods derived from contiguous measured data. The mean, standard deviation, minimum and maximum values for each 10 min period shall be derived and stored.

The wind direction bin size shall be 10°.

Data sets shall be rejected from the database under the following circumstances:

- a) failure or degradation (e.g. due to icing) of test equipment;
- b) wind direction outside the measurement sector(s) as defined for the power performance test;
- c) mean wind speed at wind turbine meteorological mast less than 4 m/s or greater than 16 m/s;
- d) any other special atmospheric conditions that are found to influence the site calibration result and chosen to be rejection criteria;
- e) special atmospheric conditions to be used as rejection criteria during the power performance test that are found to influence the site calibration.

Any special atmospheric condition filtered during the site calibration shall also be filtered during the power curve test.

9 Analysis

9.1 General

The site calibration measures the relationship of wind speeds at two specific points in space. Orography represents a static influence on this relationship (the terrain is not moving over time) however wind shear adds a dynamic element to this relationship, as it is possible that the wind speed gradient will vary significantly according to height, or it is possible that it will not if the site only sees a fairly steady shear over a limited range.

The first step in the analysis is to assess the shear conditions at the site. The calculations and plots described in 9.2 are performed first to make this assessment, then based on the outcome either 9.3 or 9.4 is followed to complete the calculation of the flow corrections. Once the flow corrections have been calculated according to either 9.3 or 9.4, the procedure then continues with the additional calculations in 9.5 which are inputs to the uncertainty calculations in Clause 10 and the quality checks in Clause 11.

9.2 Assessment of site shear conditions

9.2.1 Shear calculations and characterisation plots

For each 10 min data point, the following calculations shall be made:

- a) the wind speed ratio, which is the wind speed at the wind turbine meteorological mast divided by the wind speed at the reference meteorological mast;
- b) the shear exponent at both meteorological masts shall be calculated using the power law (see 3.17);
- c) the time of day using a 24 h clock shall be determined from the timestamp and any offset to the site local time. Any adjustment to local clocks for more daylight hours in summer vs. winter (i.e. daylight saving time, summer time) shall be noted if it is applied to the data acquisition timestamps.

The analysis method shall depend on whether or not wind shear is determined to be a significant factor at the site. High shear, or more specifically a wide range of shear values, is typically due to a diurnal cycle of stable atmosphere at night and unstable atmosphere during the day. To illustrate the shear conditions at the site and to assist with the shear evaluation, the following scatter plots shall be generated for both the wind turbine location and reference meteorological mast data from the filtered database:

- Scatter plot of wind shear exponent vs. time of day;
- Scatter plot of wind shear exponent vs. wind direction;
- Scatter plot of wind shear exponent vs. wind speed;
- Scatter plot of wind speed vs. time of day.

Note that time of day should be used with care because the correlation to local sunrise and sunset times often strongly influence atmospheric stability. Especially for longer data sets and higher latitudes, the correlation between sunrise, sunset and time of day becomes quite poor.

For a site where these effects occur, typically the shear exponents observed during the daytime will be low as the sun heats the ground causing turbulence and mixing of the layers and at night the shear will be high. Thus, there may be a wide range of shear exponents and a noticeable change in the shear exponents from daytime to night-time for these sites.

9.2.2 Assess significance of shear

Regardless of atmospheric stability, shear shall be considered to be a significant factor if more than 25 % of the data points have a shear exponent greater than 0,25.

Shear shall be confirmed to be a significant parameter if the wind speed correlation improves following binning by wind direction and shear according to Method 1 in 9.3; otherwise the site calibration may be evaluated following Method 2 – linear regression method described in 9.4.

Dividing the measurement sector to allow for different methodologies for different sectors is permitted. This may be useful if, for example, the terrain from part of the measurement sector is Type A and from another direction it is Type B.

The goal is to ensure that the site calibration is not biased by unusual shear conditions; either the site calibration method accounts for the impact of shear or unusual conditions are filtered out. The site calibration results using method 9.3 or 9.4 may be assessed using the method in 9.5, where the site calibration flow corrections are applied to the reference meteorological mast wind speed and this is then compared to the wind turbine meteorological mast wind speed. Comparing the site calibration residuals against wind shear or other atmospheric stability metrics will show if the selected method accurately corrects the reference meteorological mast wind speed for all conditions or if additional steps are necessary to improve quality and reduce uncertainty. Specifically:

- a) The self-consistency parameter (Equation (4)) bin-averaged against wind speed should be between 0,98 and 1,02 in the range of 4 m/s to 16 m/s within each sector
- b) A linear regression of $V_{\text{Turbine_Predicted}}$ (Equation (2)) vs. $V_{\text{Turbine Measured}}$ should have an R^2 value $> 0,95$ within each sector.

9.2.3 Establish correlation of shear between locations

If shear is determined to be significant at the site and where there is a requirement to filter on shear at the wind turbine location, then it shall be established that the shear at the wind turbine location can be predicted from the shear measured at the reference meteorological mast. The simplest method to achieve this is to plot the shear at the turbine location vs. the shear at the reference meteorological mast and calculate an ordinary least squares linear regression. This shall be done using the filtered database. Note that this regression may be used during the power curve measurement to predict shear at the wind turbine location.

If the shear at the wind turbine location and the shear at the reference meteorological mast are not correlated for all cases, then steps shall be taken so that the data is correlated for all cases. For example, non-correlation may occur where there is a significant difference in elevation between the reference meteorological mast and wind turbine location in conjunction with high shear, which is often correlated with time of day. In these cases, the suggested method to achieve correlated results is to filter the data based on time of day to remove the high shear night-time data, although other methods to remove non-correlating data are permitted. The time-of-day filter may be established using the shear exponent vs. time-of-day plots. Reducing the measurement sector such that only directions with similar flow conditions are considered, filtering or breaking the site calibration up by seasons, or other methods to achieve a fully correlated data set may be used. The plots of shear exponent vs. wind direction may be useful in determining which sectors to use.

Any additional filter applied to the site calibration results shall also be applied to the power curve measurement. If a time-of-day filter is used, the filter may be adjusted seasonally to reflect longer days during the summer and shorter days during the winter. Only data from the reference meteorological mast should be used for any additional filters because it will not be possible to filter on the turbine location data during the power curve measurement.

Shear, turbulence, and wind speed are often correlated. The plots of wind shear exponent vs. wind direction, wind shear exponent vs. wind speed, and wind speed vs. time of day may be used to assess the potential impact of these filters on the power curve data in terms of reduced data at certain wind speeds. For example, if applying a time-of-day filter will result in the loss of most of the data at high wind speeds, then it is possible that this filter will not be practical. In the extreme case a solution could be to have multiple site calibrations, each valid for a specific range of atmospheric conditions.

9.3 Method 1: Bins of wind direction and wind shear

To determine if the site calibration flow corrections are influenced by the shear on the site, the data shall be sorted into bins of wind direction and shear. The size of the wind direction bins shall be 10° and shall not be less than the uncertainty of the wind direction sensor. At the edges of the measurement sector, the data shall be filtered to the extents of the measurement sector. For example, where the measurement sector ends at 43° , the site calibration at the edge of the sector will be evaluated from 35° to 43° only. It is required that the choice of wind direction bin centre definition (e.g. either bins centred on integer multiples of 10° or bins beginning on integer multiples of 10°) shall be carried through consistently from the site calibration to the power curve test. The wind shear bins shall be in increments of 0,05 shear exponent centred on integer multiples of 0,05.

The wind speed ratios within each wind direction and wind shear bin shall be averaged.

The completion criteria for the wind direction and wind shear bins are as follows:

- a) For each wind direction bin, the number of data points across all wind shear bins within that wind direction bin shall total at least 144 (24 h of data). Incomplete wind shear bins may be included in this total. Furthermore, each wind direction bin shall contain at least 6 h above and 6 h below 8 m/s.
- b) Each wind shear bin within a complete wind direction bin shall contain at least 3 data points.
- c) Wind shear bins in incomplete wind direction sectors that contain at least 6 h of data may also be considered complete.

If after the matrix has been completed it is found that the site calibration flow corrections do not change with increasing wind shear, then the wind shear bins may be eliminated, and the data evaluated only on a wind direction bin basis according to 9.4. The level of change shall be evaluated against the statistical uncertainty of the site calibration.

If the variation between wind shear bins causes a level of variability in site calibration flow corrections that is higher than twice the statistical uncertainty of the site calibration in one or more wind direction bins, the wind shear bins shall be included in the analysis alongside the wind direction bins.

If the variation between wind shear bins causes a level of variability in site calibration flow corrections that is lower than twice the statistical uncertainty of the site calibration in one or more wind direction bins, the wind shear bins may be eliminated, and the data evaluated only on a wind direction basis per 9.4.

During the power curve measurement, the data shall be sorted into wind direction bins. For each 10 min data point, the wind shear exponent at the reference meteorological mast shall be calculated. The flow correction applied to the reference wind speed shall be the wind speed ratio interpolated to the measured wind shear value from the wind shear bin average values and the measured wind shear exponent for that wind direction bin. Extrapolation is permitted for wind shear exponents falling within the last complete wind shear bins; for example, if the last complete site calibration wind shear bin is the 0,6 wind shear bin, extrapolation is permitted for measured wind shear exponent values between 0,600 and 0,625 (where 0,625 is the upper edge of the 0,6 wind shear bin with a bin width of 0,05 and a range of 0,575 to 0,625). Interpolation between two complete wind shear bins across an incomplete wind shear bin is permitted. Interpolation between wind direction bins is not permitted.

9.4 Method 2: Linear regression method where wind shear is not a significant influence

The data sets shall be sorted into wind direction bins. The size of the wind direction bins shall be 10° . It is required that the choice of direction bin centre definition (e.g. either bins centred on integer multiples of 10° or bins beginning on integer multiples of 10°) shall be carried through consistently from the site calibration to the power curve test. At the edges of the measurement

sector, the data shall be filtered to the extents of the measurement sector. For example, where the measurement sector ends at 43°, the site calibration at the edge of the sector will be evaluated from 35° to 43° only.

For each wind direction bin an ordinary least squares linear regression shall be made with the wind turbine location wind speed as the dependent variable and the reference meteorological mast wind speed as the independent variable. Therefore, there will be one slope and one intercept for each wind direction bin.

Each wind direction bin shall have at least 24 h of data in total and shall have at least 6 h of data where winds are above 8 m/s and at least 6 h of data where winds are below 8 m/s. There should be a wide distribution of wind speeds within the bin to get a good correlation (see 11.2), and it is therefore recommended that data with wind speeds at least up to 11 m/s be present. Note that outliers are highly weighted by the ordinary least squares regression method. Any outliers that appear to have a significant impact on the regression should be investigated and documented.

To illustrate the correlation between the reference meteorological mast and turbine location wind speed, the following plots shall be generated for each complete wind direction bin within the measurement sector:

- a) wind turbine location wind speed vs. reference meteorological mast wind speed, including an indication of the linear regression and correlation coefficients (commonly known as the R^2 value).

On a single axis, plot the following (see Figure B.9 for an example):

- b) wind speed ratio vs. reference meteorological mast wind speed;
- c) bin averages of the wind speed ratios in 0,5 m/s wind speed bins;
- d) a curve $y = m + b/x$ where m is the slope of the linear regression, b is the intercept and x is the reference meteorological wind speed, and y is the predicted turbine location wind speed normalized to the reference meteorological mast wind speed, i.e. y = the wind speed ratio;
- e) a horizontal line indicating the average of all wind speed ratios within the wind direction bin.

9.5 Additional calculations

The site calibration flow corrections shall be applied to the reference meteorological mast data to calculate the predicted wind turbine location wind speed for each data point. This shall be done using the filtered database.

$$V_{\text{Turb_predicted}} = F(\text{WD}, \alpha) \cdot V_{PM} \quad (2)$$

where

- $V_{\text{Turb_predicted}}$ is predicted wind turbine location wind speed;
- $F(\text{WD}, \alpha)$ is site calibration flow correction determined in 9.3;
- V_{PM} is reference meteorological mast wind speed;
- WD is wind direction bin;
- α is wind shear exponent, if applicable.

A site calibration residual shall be calculated as follows for each 10 min data point as the difference between the predicted wind turbine location wind speed and the measured wind turbine location wind speed.

$$\text{residual} = V_{\text{Turb_predicted}} - V_{\text{Turb_measured}} \quad (3)$$

A self-consistency parameter shall be calculated as follows for each 10 min data point: divide the predicted wind turbine location wind speed by the measured wind turbine meteorological mast wind speed.

$$\text{self_consistency_parameter} = \frac{V_{\text{Turb_predicted}}}{V_{\text{Turb_measured}}} \quad (4)$$

The residuals and the self-consistency parameter are used to assess the variation and any biases in the results. The mean of the residuals and self-consistency parameter reflect the mean bias, where mean values of 0 and 1,0 translate to zero bias, respectively. The standard deviation of these parameters is indicative of the variation around the mean bias, and is used for the calculation of the statistical uncertainty of the site calibration.

In addition to the statistical uncertainty calculations, which are based on the variation about an assumed mean bias of zero, these parameters are used for calculation of additional uncertainty to be added in certain scenarios listed in Clause 11, which are based on assessments of the estimated mean bias introduced by the scenario which are reflected in shifts in the mean of these parameters away from 0 and 1,0, respectively.

10 Site calibration uncertainty

10.1 Site calibration category A uncertainty

10.1.1 Site calibration K -fold analysis

The site calibration trains a model to predict the wind speed at the wind turbine location based on the wind speed at the reference meteorological mast location. To avoid the risk of under-estimating the category A uncertainty due to over-fitting the model to the data, the category A uncertainty shall be calculated using k -fold cross validation with $k = 10$. Note that in the wind industry, k has different meanings, however the use of the term " k " here is consistent with its use in statistical learning, as the method applied is known as " k -fold cross validation".

The final filtered data set shall be divided into k equally sized folds (partitions) based on timestamp.

For each fold ($k = 1$ through 10):

- a) The site calibration flow corrections shall be calculated according to Clause 9 using only data from the other 9 folds.
- b) The site calibration flow corrections shall be used to calculate the predicted wind speed at the turbine location using the reference meteorological mast wind speeds measured during fold k .
- c) The predicted turbine location wind speeds in fold k shall be compared to the actual measured turbine location wind speeds in fold k according to both the residual and self-consistency parameters defined in 9.5.
- d) The statistical uncertainty for fold k shall be determined per 10.1.2.

The total category A uncertainty is the square root of the sum of the squares of the uncertainty calculated for each fold divided by the square root of k .

$$s_{VT} = \sqrt{\frac{\sum_{i=1}^k s_{VT,i}^2}{k}} \quad (5)$$

A value of $k = 10$ is chosen so that there is a higher probability that there will be sufficient information in the remaining sets to cover the range of wind speeds present in the data set being evaluated, however other values of k are allowed so long as $k \geq 2$.

The folds are divided by timestamp rather than being randomly chosen since it is expected that the variations in relationship in wind speeds between the two locations may be correlated with meteorological events which are correlated with time, and so folds that are time based are more likely to better capture variation between the conditions during the site calibration and the power curve measurement time periods.

10.1.2 Site calibration statistical uncertainty for each fold

For each fold in the k -fold cross validation, the deviation between the site calibration flow corrected wind speed at the wind turbine location and the wind speed measured at the wind turbine location is calculated for each 10 min period, and the standard deviation of the wind speed deviation over all 10 min periods is calculated as follows:

$$d_{\text{std},k} = \sqrt{\frac{\sum_{j=1}^N (d_{j,k} - \bar{d}_k)^2}{N_k - 1}} \quad (6)$$

where

$d_{j,k}$ is the residual in the j -th 10 min period of fold k , see Equation (3);

$\bar{d}_k$ is the mean value of the residuals in fold k ;

N_k is the number of data sets in fold k ;

$d_{\text{std},k}$ is the standard deviation of site calibration residuals in fold k .

Only data that has been included in the assessment of the site calibration shall be included in the calculation of the standard deviation.

The statistical, category A, standard uncertainty of fold k is:

$$s_{\text{VT},k} = d_{\text{std},k} \cdot \frac{\sqrt{N_k - 1}}{\sqrt{f \cdot N_k}} \quad (7)$$

where

f is number of degrees of freedom of the site calibration.

The number f is the number of 10 min periods included in the site calibration minus the total number of parameters of the site calibration algorithm. In the case where the site calibration flow corrections are in the form of bin-averaged wind speed ratios, the number of parameters of the site calibration algorithm per wind direction sub-sector equals the number of wind shear bins. The value of f is then N_k minus the number of wind direction sub-sectors (normally number of 10° wide sectors). In the case where the site calibration flow corrections are in the form of linear regressions (slopes and offsets), the number of parameters of the site calibration algorithm is 2 per wind direction sub-sector. The value of f is then N_k minus twice the number of wind direction bins. In the case where the site calibration flow corrections are in the form of bin-averaged wind speed ratios per wind direction and wind shear bin, f is N_k minus the sum of the number of all wind shear bins in all wind direction sub-sectors.

10.2 Site calibration category B uncertainty

10.2.1 General

The following components of uncertainty should be considered to be independent of each other in evaluating the combined category B standard uncertainty.

10.2.2 Anemometer – Pre-calibration

This uncertainty component covers the uncertainty related to the calibration of the sensors before the test.

The symbol for this uncertainty component is $u_{VT,precal,i}$.

This uncertainty is discussed in IEC 61400-50-1.

The anemometer calibration standard uncertainty shall be taken from the calibrations. Where the anemometer calibrations on the reference meteorological mast and wind turbine location have been performed in the same tunnel, the estimated uncertainties are correlated to some extent; the same is true for calibrations of the anemometer(s) used for the power performance testing. A practical approach is to include the magnitude of one calibration uncertainty if the calibrations are done in the same wind tunnel. Where the calibrations have been done in different wind tunnels or different model anemometers are used, the uncertainties are independent and shall be taken into account as such.

The following specific guidance is given. If the reference anemometer is not exchanged between site calibration and the power curve test, its calibration uncertainty cancels out completely. Only the turbine mast anemometer calibration uncertainty is then relevant. If the reference anemometer is exchanged between the site calibration and the power curve test for an anemometer calibrated in the same wind tunnel as used for the calibration of the first anemometer, a big part of the calibration of the reference anemometers cancels out if the wind tunnel gives highly reproducible results. If the reference anemometer is exchanged between the site calibration and the power curve test for an anemometer calibrated in a different wind tunnel to that used for the calibration of the first anemometer, the uncertainty of both anemometer calibrations is relevant.

10.2.3 Anemometer – Post-calibration

This uncertainty component covers the uncertainty related to the in-situ calibration (IEC 61400-50-1) and/or the post-calibration of the sensor (IEC 61400-50-1) during and/or after the site calibration.

The symbol for this uncertainty component is $u_{VT,postcal,i}$.

This uncertainty is discussed in IEC 61400-50-1.

10.2.4 Anemometer – Classification

This uncertainty component covers the uncertainty related to the classification of the sensors for the site calibration according to IEC 61400-50-1.

The symbol for this uncertainty component is $u_{VT,class,i}$.

This uncertainty is virtually the same as $u_{VS,class,i}$ with the difference that in this document it is applied to a measurement of wind speeds on two masts. Some of the influence factors for the classification will be experienced in the same way by both sensors, causing a correlation in the operational response and a reduction in the difference between the signals. But major influence factors such as turbulence, shear and upflow may be different between the two measurement

locations and as such the magnitude of this uncertainty component shall be set to equal the uncertainty related to the classification of the anemometer on the wind turbine location meteorological mast.

The magnitude of this uncertainty shall be taken from the classification report. The terrain type in which the sensor is used shall match the terrain type of the classification of the sensor (Class A, B or S).

A reference to the classification report shall be included in the site calibration report. If no such reference is included, the default magnitude for the uncertainty shall be a class 3,4A (for non-complex terrain) or a class 4,5B (for complex terrain).

The measured range of the influence parameters used for the classification as per IEC 61400-50-1 shall be reported for the same data set used for the site calibration report. If upflow is not measured, compliance with the accuracy class shall be argued from the local terrain slopes for the experienced wind directions, assuming that the vertical angle of the wind is 2/3 of the average terrain slope within 5D of the turbine upwind of the turbine.

10.2.5 Anemometer – Mounting

This uncertainty component covers the uncertainty related to the mounting of the sensors according to IEC 61400-50-1 during the site calibration. The wind turbine location anemometer as well as the reference meteorological mast anemometer mounting standard uncertainty shall be taken into account in the site calibration uncertainty evaluation.

The symbol for this uncertainty component is $u_{VT,mnt,i}$.

This uncertainty is virtually the same as $u_{VS,mnt,i}$ with the difference that in this document it is applied to a measurement of wind speeds on two masts. If the sensors are of the same type, the mast layout is the same and the wind direction is the same, one could assume that a high correlation exists between the mounting influences from both masts on both sensors which would be grounds for a reduced uncertainty. However, even with the same sensor type and mast layout often the wind direction that is experienced simultaneously on both masts will not be the same. As the influence from the mast on the sensors is directionally sensitive, the actual correlation of mounting effects between both masts will be limited and the mounting effects need to be taken into account.

The default magnitude for this uncertainty component for each of the three possible mounting arrangements (single top mount, side-by-side top mount or side mounted) are defined in IEC 61400-50-1.

10.2.6 Anemometer – Data acquisition

This uncertainty component covers the uncertainty related to the data acquisition of the signals of the wind speed sensors according to IEC 61400-50-1 during the site calibration.

The symbol for this uncertainty component is $u_{dVT,i}$.

This uncertainty is virtually the same as $u_{dVS,i}$ with the difference that here it is applied to a measurement of wind speeds on two masts. As the data acquisition of both signals is assumed independent, this uncertainty needs to be counted twice.

The default magnitude for this uncertainty component is 0,1 % to 0,2 % of the full range of the wind speed measurement channel.

10.2.7 Anemometer – Lightning finial

This uncertainty component covers the uncertainty related to a possible top-mounted lightning finial and its influence on a top-mounted anemometer when the requirements in IEC 61400-50-1 for the mounting of the lightning finial cannot be met.

The symbol for this uncertainty component is $u_{VT,igt,i}$.

This uncertainty is virtually the same as $u_{VS,igt,i}$ with the difference that in this document it is applied to a measurement of wind speeds on two masts. If the sensors are of the same type, the mast layout is the same and the wind direction is the same, one could assume that a high correlation exists between the mounting influences from both masts on both sensors which would be grounds for a reduced uncertainty. However, even with the same sensor type and mast layout often the wind direction that is experienced simultaneously on both masts will not be the same. As the influence from the lightning finial on the sensors is directionally sensitive, the actual correlation of mounting effects between both masts will be limited and the lightning finial effects (when the requirements for the finial of IEC 61400-50-1 cannot be met) need to be taken into account.

Refer to IEC 61400-50-1 for details of this component.

10.3 Combining uncertainties in the wind speed measurement from flow distortion due to site calibration $u_{VT,i}$

The following uncertainty components are combined to calculate the category B uncertainty for a site calibration, $u_{VT,i}$:

$$u_{VT,i,j} = \sqrt{u_{VT,precal,i,j}^2 + u_{VT,postcal,i,j}^2 + u_{VT,class,i,j}^2 + u_{VT,mnt,i,j}^2 + u_{VT,igt,i,j}^2 + u_{VT,coc,i,j}^2 + u_{VT,rmv,i,j}^2 + u_{VT,sv,i,j}^2 + u_{dVT,i,j}^2 + s_{VT}^2} \quad (8)$$

where

$u_{VT,i,j}$	is the uncertainty from the site calibration;
$u_{VT,precal,i,j}$	is the uncertainty related to the calibration of the anemometers;
$u_{VT,postcal,i,j}$	is the uncertainty related to the post calibration or in-situ calibration of the anemometers;
$u_{VT,class,i,j}$	is the uncertainty related to the classification of the sensors;
$u_{VT,mnt,i,j}$	is the uncertainty related to the mounting of the sensors;
$u_{VT,coc,i,j}$	is the uncertainty related to the change of correction value between bins;
$u_{VT,rmv,i,j}$	is the uncertainty related to the removal of the wind direction sensor between site calibration and power performance test;
$u_{VT,sv,i,j}$	is the uncertainty related to the seasonal variation between site calibration and power performance test;
$u_{dVT,i,j}$	is the uncertainty related to the data acquisition of the wind speed signal;
s_{VT}	is the category A standard uncertainty of the site calibration.

To obtain the uncertainty in one wind speed bin across all the directional sectors the weighted average shall be used:

$$u_{VT,i} = \frac{\sum_j u_{VT,i,j} N_{i,j}}{\sum_j N_{i,j}} \quad (9)$$

10.4 Combined uncertainty

The Category A and B components of uncertainty should be considered as independent of each other for the purpose of evaluating the combined uncertainty of the site calibration.

Narrowing the measurement sector with the goal of reducing uncertainty by eliminating higher uncertainty wind direction bins is permitted.

11 Quality checks and additional uncertainties

11.1 Convergence check

A convergence check shall be carried out using the self-consistency parameter from Equation (4) for each wind direction bin. The most illustrative graph for this purpose plots cumulative average of the self-consistency parameter against the number of hours per wind direction bin. The cumulative averages should be seen to converge to within 0,5 % of the final average within the larger of 16 h of data or 25 % of the total number of data points in that bin. If these criteria are not met, steps such as additional filtering may be applied to try to explain and correct the non-convergence. If these steps do not result in convergence, the self-consistency check according to Annex A may be performed during the power curve measurement to assess if the non-convergence is an issue. If criteria for the self-consistency check during the power curve test are not met, then the bin shall be excluded from the measurement sector.

The k -fold cross validation method used to calculate the statistical uncertainty for the site calibration should reflect a higher test uncertainty for any non-convergence, so no uncertainty penalty is applied for this check.

11.2 Correlation check for linear regression (see 9.4)

For each wind direction bin, the level of correlation shall be assessed based on the correlation coefficient of the regression, commonly known as the r value. This assessment shall be included in the report.

11.3 Change in correction between adjacent wind direction bins

11.3.1 General

It is recommended that wind direction bins from the measurement sectors be eliminated when flow corrections change by more than 2 % between neighbouring bins.

The symbol for this uncertainty component is $u_{VT,COC,i}$ (COC stands for "change in correction").

This shall be evaluated by applying the self-consistency parameter method from 9.5 as follows:

- a) Evaluate the data and calculate the site calibration flow corrections.
- b) Shift the site calibration flow corrections by one direction sector so that the flow corrections or regressions are applied to the adjacent wind direction bin. For example, if the flow correction applied to the 290° bin is $1,024x + 0,1$, then apply this correction instead to the 280° bin.
- c) Using the adjusted site calibration flow corrections from the previous step and the site calibration data, calculate the predicted wind turbine location wind speed for each 10 min period and then calculate the self-consistency parameter with Equation (4).
- d) Average the self-consistency parameters for each wind direction bin. If the average is less than 0,98 or greater than 1,02, then those wind direction bins should be eliminated. If those wind direction bins are not eliminated, then the uncertainty in those bins shall be increased by the value of 1 minus the average self-consistency parameter multiplied by 100 % and

divided by 2 and the square root of 3. If a sector has this applied from both adjacent sectors, then the increase in uncertainty is the average of the two.

This method shall be applied by both adding and subtracting to the wind direction bin, for example applying the 290° bin results to both the 280° and 300° bins. The uncertainty adjustment for bins not on the edge shall be the average impact of moving one adjacent bin in each direction.

$$u_{VT,coc,i,j} = \frac{1}{2} \cdot \left(\frac{|1 - sccp_{j,j-1}|}{2\sqrt{3}} + \frac{|1 - sccp_{j,j+1}|}{2\sqrt{3}} \right) \quad (10)$$

where:

- $u_{VT,coc,i,j}$ is the standard uncertainty due to change in correction in wind direction bin j ;
- $sccp_{j,j-1}$ is the site calibration consistency parameter for wind direction bin j using the site calibration flow corrections in bin $j - 1$;
- $sccp_{j,j+1}$ is the site calibration consistency parameter for wind direction bin j using the site calibration flow corrections in bin $j + 1$.

For sub-sectors at the edges of the measurement sector the uncertainty shall be assessed only by applying the correction from the respective neighbouring sub-sector.

11.3.2 Removal of the wind direction sensor between site calibration and power performance test

If the wind direction sensor is removed between site calibration and the power performance test, an error may be introduced due to the uncertainty of the wind direction sensor alignment between the two installations. An additional uncertainty component for each wind direction bin shall be applied.

The symbol for this uncertainty component is $u_{VT,rmv,i}$.

This uncertainty component shall be calculated for each wind direction bin as follows:

- a) For each wind direction bin apply the method in 11.3 except that the uncertainty will also be applied where the average of the self-consistency parameters is between 0,98 and 1,02.
- b) Determine the relative uncertainty in the wind direction measurements.
- c) Multiply the result of list item a) by the ratio of the relative uncertainty in the wind vane measurements to the total wind direction bin size.

For example, the wind vane fails and is replaced by a similar model between site calibration and power curve measurement. The uncertainty in the wind vane alignments is determined to be 3° and the bin size is 10°. Multiply the change in correction between adjacent bins from 11.3 by $\frac{3}{10}$. This uncertainty is applied in addition to any uncertainty applied due to 11.3.

$$u_{VT,rmv,i,j} = u_{VT,coc,i,j} \cdot \left(\frac{u_{w,i}}{\text{BinSize}_j} \right) \quad (11)$$

where:

- $u_{w,i}$ is the wind direction uncertainty calculated according to IEC 61400-12-1;
- BinSize is the bin size of wind direction bin j , e.g. 10°.

Note that $u_{w,i}$ may be evaluated on a relative basis, i.e. uncertainty components that are fully correlated between the site calibration and power curve measurement may be neglected. For example if the met mast remains in place and only the sensor is replaced on the same boom and mount with an identical make and model, $u_{WVbo,i}$ and $u_{WVoe,i}$ may be neglected.

11.4 Site calibration and power performance measurements in different seasons

Seasonal changes in wind conditions and changes in surface roughness due to vegetation, precipitation (snow and ice) and freezing of bodies of water may cause a seasonal dependency in the site calibration flow corrections. It is therefore recommended that the site calibration and power performance measurements be conducted in the same part of the year, for example both occurring in summer. To assess the possible impact of this the following steps shall be taken.

The average wind conditions at the reference meteorological mast during the site calibration (wind shear, turbulence, upflow) shall be compared to the average wind conditions at the same meteorological mast during the power performance measurement for the wind directions within the measurement sector. An additional uncertainty shall be calculated for seasonal effects if any of these conditions for a wind direction bin differs by more than the following amounts:

- a) 0,05 for wind shear exponent;
- b) 3 % for turbulence intensity;
- c) if upflow is measured, a limit of $\pm 2^\circ$ change in vertical upflow is recommended.

The symbol for this uncertainty component is $u_{VT,sv,i}$. The additional uncertainty for seasonal effects shall be calculated as one third of the magnitude of the site calibration flow correction.