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IEC 61400-12-3

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INTERNATIONAL STANDARD

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colour inside

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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CONTENTS

FOREWORD 5
INTRODUCTION 7
1 Scope 8
2 Normative references 8
3 Terms and definitions 8
4 Symbols, units and abbreviated terms 10
5 General 12
6 Overview of the procedure 13
7 Test set-up 14
7.1 Considerations for selection of the test wind turbine and location of the meteorological mast 14
7.1.1 General 14
7.1.2 Type A: 14
7.1.3 Type B: 14
7.1.4 Type C: 15
7.2 Instrumentation 15
8 Data acquisition and rejection criteria 16
9 Analysis 17
9.1 General 17
9.2 Assessment of site shear conditions 17
9.2.1 Shear calculations and characterisation plots 17
9.2.2 Assess significance of shear 17
9.2.3 Establish correlation of shear between locations 18
9.3 Method 1: Bins of wind direction and wind shear 19
9.4 Method 2: Linear regression method where wind shear is not a significant influence 19
9.5 Additional calculations 20
10 Site calibration uncertainty 21
10.1 Site calibration category A uncertainty 21
10.1.1 Site calibration K-fold analysis 21
10.1.2 Site calibration statistical uncertainty for each fold 22
10.2 Site calibration category B uncertainty 23
10.2.1 General 23
10.2.2 Anemometer – Pre-calibration 23
10.2.3 Anemometer – Post-calibration 23
10.2.4 Anemometer – Classification 23
10.2.5 Anemometer – Mounting 24
10.2.6 Anemometer – Data acquisition 24
10.2.7 Anemometer – Lightning finial 25
10.3 Combining uncertainties in the wind speed measurement from flow distortion due to site calibration $u_{\mathrm{VT,i}}$ 25
10.4 Combined uncertainty 26
11 Quality checks and additional uncertainties 26
11.1 Convergence check 26
11.2 Correlation check for linear regression (see 9.4) 26
11.3 Change in correction between adjacent wind direction bins 26

iTeh STANDARD PREVIEW
(standards.iteh.ai)
IEC 61400-12-3:2022

11.3.1 General 26
11.3.2 Removal of the wind direction sensor between site calibration and power performance test 27
11.4 Site calibration and power performance measurements in different seasons 28
Annex A (informative) Verification of results 29
Annex B (informative) Site calibration examples 31
B.1 Example A 31
B.1.1 Site description: 31
B.1.2 Site calibration setup: 31
B.1.3 Site calibration evaluation: 31
B.1.4 Step 1: Check the significance of wind shear at the site according to 9.2.2: 31
B.1.5 Step 2: Verify correlation of wind shear at wind turbine and reference meteorological mast locations – Example A 32
B.1.6 Step 3: Calculate results according to 9.2.3 33
B.1.7 Step 4: Quality checks and additional uncertainties 33
B.2 Example B 35
B.2.1 Site description: 35
B.2.2 Site calibration setup: 35
B.2.3 Step 1: Check the significance of wind shear at the site: 36
B.2.4 Step 2A: Verify correlation of wind shear at wind turbine and reference meteorological mast locations, example B 36
B.2.5 Step 2B: Attempt to remove non-correlating wind shear data 38
B.2.6 Step 3: Calculate results 39
B.2.7 Step 4: Additional uncertainties: 39
B.3 Example C 41
B.3.1 Site description: 41
B.3.2 Site calibration setup: 41
B.3.3 Step 1: Check the significance of wind shear at the site: 42
B.3.4 Step 2: Verify correlation of wind shear at wind turbine and reference meteorological mast locations, example C 42
B.3.5 Step 3: Calculate results 42
B.3.6 Step 4: Quality checks and uncertainty 42
B.3.7 Anemometer operational uncertainty: 42
B.3.8 Convergence check: 42
B.3.9 Change in magnitude of correction between bins: 43
B.3.10 Wind vane adjustment: 43
B.3.11 Seasonal uncertainty adjustment: 43
Bibliography 44

Figure 1 – Site calibration flow chart 13
Figure 2 – Terrain types 15
Figure A.1 – Example of the results of a verification test 30
Figure B.1 – Wind shear exponent vs. time of day, Example A 32
Figure B.2 – Wind shear exponents at wind turbine location vs. reference meteorological mast, example A where the colour axis = wind speed (m/s) 32
Figure B.3 – Wind speed ratios and number of data points vs. wind shear exponent and wind direction bin – wind speed ratios (full lines), number of data points (dotted lines) 33

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IEC 61400-12-3:2022
https://standards.iteh.ai/catalog/standards/sist/5262f8d1-e0cc-47a3-9f0c-b428d325994c/iec-61400-12-3-2022

Figure B.4 – Data convergence check for 190° bin 35
Figure B.5 – Wind shear exponent vs. time of day, example B 36
Figure B.6 – Wind shear exponents at wind turbine location vs. reference meteorological mast, example B 36
Figure B.7 – Linear regression of wind turbine location vs. reference meteorological mast hub height wind speeds for 330° bin 37
Figure B.8 – Wind speed ratios vs. wind speed for the 330° bin 37
Figure B.9 – Wind speed ratios vs. wind shear for the 330° bin 38
Figure B.10 – Wind shear exponents at wind turbine location vs. reference meteorological mast post-filtering 38
Figure B.11 – Linear regression of wind turbine location vs. reference meteorological mast hub height wind speeds for 330° bin, post-filtering 39
Figure B.12 – Wind speed ratios vs. wind speed for the 330° bin, post-filtering 39
Figure B.13 – Data convergence check for 330° bin 40
Figure B.14 – Site calibration wind shear vs. power curve test wind shear 41
Figure B.15 – Convergence check for 270° bin 43

Table B.1 – Site calibration flow corrections (wind speed ratio) 34
Table B.2 – Site calibration data count 34
Table B.3 – r^2 values for each wind direction bin 40
Table B.4 – Additional uncertainty due to change in bins for example B 40
Table B.5 – Additional uncertainty due to change in bins for example C 43

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IEC 61400-12-3:2022
https://standards.iteh.ai/catalog/standards/sist/5262f8d1-e0cc-47a3-9f0c-b428d325994c/iec-61400-12-3-2022

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WIND ENERGY GENERATION SYSTEMS –

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

FOREWORD

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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,
- replaced by a revised edition, or
- 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.

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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.

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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*

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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

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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

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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.

61400-12-3-2022

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

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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

$$v_{\mathrm{z}i} = v_{\mathrm{h}} \left(\frac{z_i}{H} \right)^{\alpha} \tag{1}$$

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where

v_{h} is the hub height wind speed;

H is the hub height (m);

$v_{\mathrm{z}i}$ 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]
$d_{\mathrm{std},k}$	standard deviation of site calibration residuals in fold k	[W]
$\overline{d}_k$	mean value of the residuals in fold k	[W]
F(WD,α)	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]
$s_{\mathrm{VT},i}$	category A standard uncertainty of site calibration in bin i	[m/s]
$s_{\mathrm{VT},k}$	category A standard uncertainty of site calibration of fold k site calibration consistency parameter for wind direction bin j	[m/s]
$\mathrm{sccp}_{j,j\text{-}1}$	site calibration consistency parameter for wind direction bin j using the site calibration correction in bin j-1	[°]
$\mathrm{sccp}_{j,j+1}$	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	
$u_{\mathrm{dVT},i}$	category B standard uncertainty for data acquisition	[m/s]
$u_{\mathrm{dVT},i,j}$	uncertainty related to the data acquisition of the wind speed signal	
$u_{\mathrm{VT,class},i}$	category B standard uncertainty for anemometer operational characteristics	[m/s]
$u_{\mathrm{VT,class},i,j}$	uncertainty related to the classification of the sensors	
$u_{\mathrm{VT,coc},i,j}$	category B standard uncertainty for change in correction to wind direction bin j	[°]
$u_{\mathrm{VT},i,j}$	uncertainty from the site calibration	
$u_{\mathrm{VT,lgt},i}$	uncertainty related to the lightning finial	[m/s]
$u_{\mathrm{VT,mnt}i}$	category B standard uncertainty for anemometer mounting effects	[m/s]
$u_{\mathrm{VT,mnt},i,j}$	uncertainty related to the mounting of the sensors	
$u_{\mathrm{VT,precal},i}$	category B standard uncertainty for anemometer calibration	[m/s]
$u_{\mathrm{VT,precal},i,j}$	uncertainty related to the calibration of the anemometers	
$u_{\mathrm{VT,postcal},i,j}$	uncertainty related to the post calibration or in-situ calibration of the anemometers	
$u_{\mathrm{VT,rmv},i,j}$	category B standard uncertainty for removal of wind direction sensor between site calibration and power performance test	[°]
$u_{\mathrm{VT,sv},i}$	uncertainty component related to seasonal variation	
$u_{\mathrm{VT,sv},i,j}$	uncertainty related to the seasonal variation between site calibration and power performance test	
$u_{\mathrm{w},i}$	category B standard uncertainty for the wind direction sensor	[°]
V_{PM}	reference meteorological mast wind speed	[m/s]
$V_{\mathrm{Turb\_measured}}$	measured wind turbine location wind speed	[m/s]
$V_{\mathrm{Turb\_predicted}}$	predicted wind turbine location wind speed	[m/s]
v_{h}	hub height wind speed	[m/s]
$v_{\mathrm{z}i}$	wind speed at height z_i	
WD	wind direction bin	[°]
WME	wind measurement equipment	
α	wind shear exponent from power law	

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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.

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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.

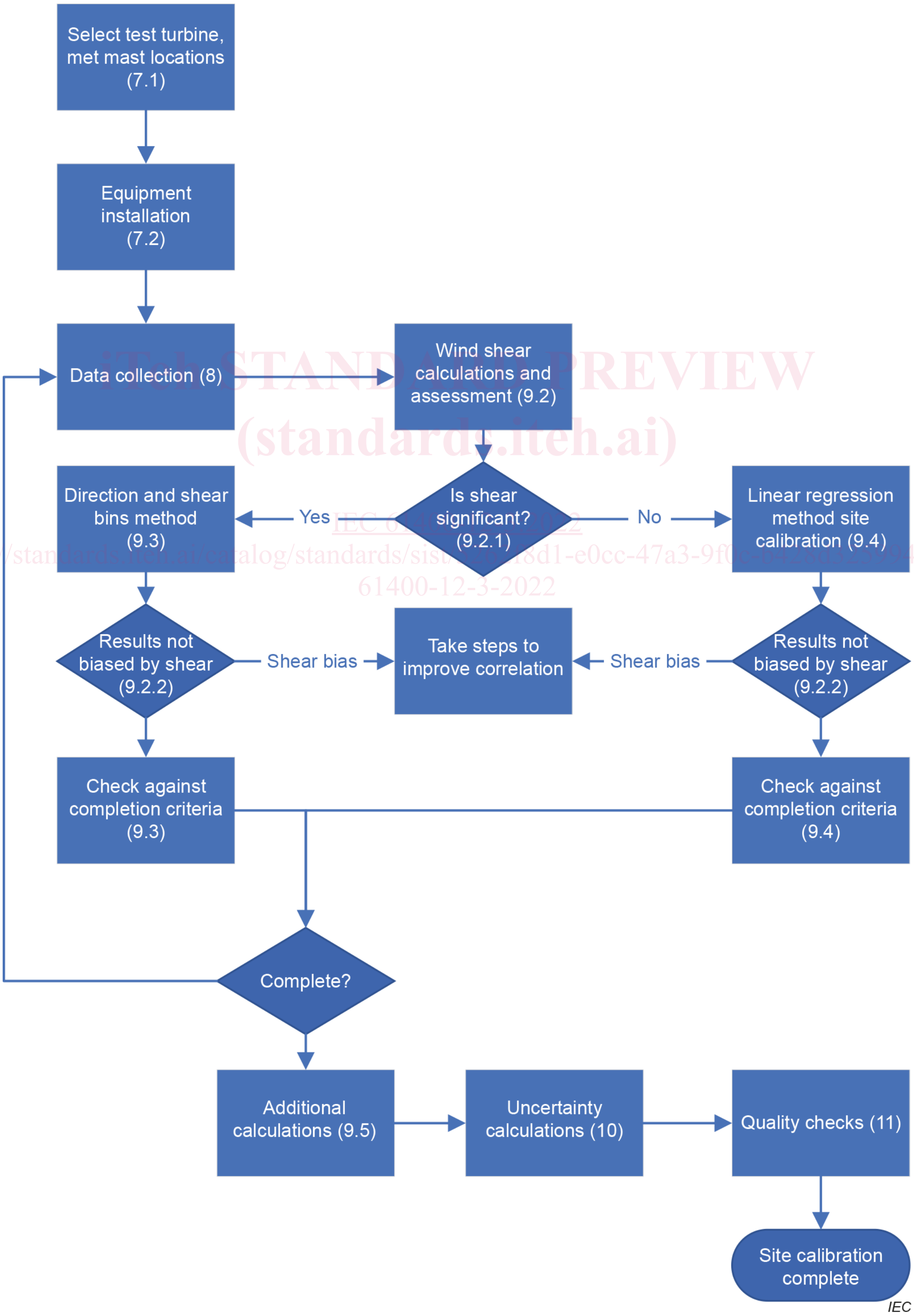

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Figure 1 – Site calibration flow chart