IEC 61400-50-2

Edition 1.0 2022-08

INTERNATIONAL STANDARD

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Wind energy generation systems –
Part 50-2: Wind measurement – Application of ground-mounted remote sensing technology

Systèmes de génération d'énergie éolienne –
Partie 50-2: Mesurage du vent – Application de la technologie de télédétection montée au sol

IEC 61400-50-2:2022-08(en-fr)

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FOREWORD

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IEC 61400-50-2 has been prepared by IEC technical committee 88: Wind energy generation systems. It is an International Standard.

This first edition of IEC 61400-50-2 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
88/829/CDV	88/865/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/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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of IEC 61400 specifies procedures and methods which ensure that wind measurements using ground-mounted remote sensing devices are carried out and reported consistently and in accordance with best practice. This document does not define the purpose or use case of the wind measurements. However, as this document forms part of the IEC 61400 series of standards, it is anticipated that the wind measurements will be used in relation to some form of wind energy testing or resource assessment.

The main clauses of this document are not mutually dependent. Therefore, it is possible that a user will refer to only certain of the main clauses rather than all clauses to adapt this document to their specific use case. However, the main clauses are presented in a logical sequence that could be applied in practice.

The technical content of this document could previously be found in IEC 61400-12-1:2017 [1][1]. Because of the increasing complexity of this source document, IEC TC 88 decided that a re-structuring of the IEC 61400-12 series of standards into a number of more specific parts would allow more efficient management and maintenance going forward. This document has been created as part of that re-structuring process.

1 Numbers in square brackets refer to the Bibliography.

WIND ENERGY GENERATION SYSTEMS –

Part 50-2: Wind measurement – Application of ground-mounted remote sensing technology

1 Scope

IEC 61400-50 specifies methods and requirements for the application of instruments to measure wind speed (and related parameters, e.g. wind direction and turbulence intensity). Such measurements are required as an input to some of the evaluation and testing procedures for wind energy and wind turbine technology (e.g. resource evaluation and turbine testing) described by other standards in the IEC 61400 series. This document is applicable specifically to the use of ground-mounted remote sensing wind measurement instruments, i.e. devices which measure the wind at some location generally above and distant from the location at which the instrument is mounted (e.g. sodars, vertical profiling lidars). This document specifically excludes other types of RSD such as forward facing or scanning lidars. This document specifies the following:

a) the procedure and requirements for classifying ground-based RSDs in order to assess the uncertainty pertaining from sensitivity of the RSD response to meteorological conditions that can vary between the RSD calibration place and time and the use case (specific measurement campaign – SMC) place and time;
b) the procedures and requirements for calibration of RSDs;
c) the assessment of wind speed measurement uncertainty;
d) additional checks of the RSD performance and measurement uncertainty during the SMC;
e) application of the wind speed uncertainty derived from the RSD calibration and classification to the measurements taken during the SMC (e.g. interpolation of uncertainty or calibration results to different heights);
f) requirements for reporting.

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

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 https://www.electropedia.org/
- ISO Online browsing platform: available at https://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
complex terrain
terrain surrounding the test site that features significant variations in topography and terrain *obstacles* (3.10) that can cause flow distortion

3.3
data set
collection of data sampled over a continuous period

3.4
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 being different from the wind speed at the wind turbine location

3.5
hub height
<of a 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.

3.6
measurement period
period during which a statistically significant database has been collected for the use case

EXAMPLE power performance test

3.7
measurement uncertainty
parameter, associated with the result of a measurement, which characterizes the dispersion of the values that could reasonably be attributed to the measurand

3.8
measurement volume
<of RSD> region within which wind flow characteristics can influence a wind speed measurement and which is defined by the scan geometry, device configuration or arrangement of the multiple beams penetrating the volume in order to acquire that measurement

3.9
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.

3.10
obstacle
obstruction that blocks the wind and creates distortion of the flow

Note 1 to entry: Buildings and trees are examples of obstacles.

3.11
pitch and roll angles
<of RSD> levelling angles

3.12
power performance
measure of the capability of a wind turbine to produce electric power and energy

3.13
probe volume
<of RSD> region from which a single constituent physical measurement of, for example, Doppler shift or radial velocity, is acquired, several of which are typically required to derive a wind speed measurement

Note 1 to entry: The probe volume is a characteristic of the basic physical interaction of the remote sensing device with the atmosphere, rather than the wind speed measurement derived from these interactions, which is determined by the flow within the measurement volume.

3.14
radial velocity
line of sight velocity
<RSD> projection of the wind speed vector onto the RSD line of sight

3.15
standard uncertainty
uncertainty of the result of a measurement expressed as a standard deviation

3.16
swept area
<horizontal axis wind turbine> projected area of the moving rotor upon a plane normal to the axis of rotation

Note 1 to entry: For teetering rotors, it is assumed that the rotor remains normal to the low-speed shaft. For a vertical axis wind turbine, it is the projected area of the moving rotor upon a vertical plane.

3.17
test site
location and surroundings where an RSD is deployed for the purpose of providing measurements as part of a test of, for example, a wind turbine or testing of the RSD

3.18
wind shear
change of wind speed with height

3.19
wind shear exponent
α
exponent 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 and can be otherwise useful. The power law equation is:

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

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.

3.20
wind veer
change of wind direction with height

4 Symbols, units and abbreviated terms

Symbol	Description	Unit
avg	10 min average	
c	slope in linear regression	m/s
d_i	data in bin i	
M	number of environmental variables considered to have a relevant influence on the accuracy of the remote sensing device according to the classification test	
m	slope in linear regression	
m_j	slope describing the sensitivity of the wind speed measurement of the remote sensing device on the environmental variable j as gained from the combination of the results from a minimum of 3 classification tests	
m_{max}	maximum slope	
m_{min}	minimum slope a month	
m_n	slope of the nth test	
N	total number of data points in dataset	
N_{CT}	number of classification tests	
n_{b}	number of bins according to the ranges of variables given in Table 3	
n_i	number of data points in bin i	
REWS	rotor equivalent wind speed	
RSD	remote sensing device	
r^2	coefficient of determination in linear regression	
SMC	specific measurement campaign	
std	standard deviation	
$u_{\text{added\_systematic},j,i}$	added category B standard uncertainty at measurement height j (not covered by the meteorological mast)	
$u_{\text{added\_systematic},1,i}$	added category B uncertainty at the height of the top of the meteorological mast	
$u_{\text{systematic},j,i}$	cumulated other category B uncertainties of the remote sensing device at height j	
$u_{\text{systematic},1,i}$	cumulated other category B uncertainties of the remote sensing device at the height of the top of the meteorological mast	
$u_{\text{ver},i}$	standard uncertainty of calibration test in bin i in accordance with 8.3	m/s
$u_{\text{VR},i}$	uncertainty components combined to calculate the category B uncertainty for wind speed measurements from an RSD	
$u_{\text{VR,class},i}$	uncertainty related to the classification of the RSD	
$u_{\text{VR,flow},i}$	uncertainty related to the flow variation across the measurement volume of the RSD	
$u_{\text{VR,isc},i}$	uncertainty due to the in-situ test	
$u_{\text{VR,mnt},i}$	uncertainty related to the mounting of the RSD	
$u_{\text{VR,mon},i}$	uncertainty related to the monitoring of the RSD	
$u_{\text{VR,ver},i}$	uncertainty due to the verification test	
$u_{\text{VRcls,mh},i}$	uncertainty due to operational characteristics of the RSD at control mast height in bin i	
$u_{\text{VRvrf,mh},i}$	uncertainty of the RSD verification at control mast height in bin i	

Symbol	Description	Unit
$V_{\text{ref},i}$	mean value of the reference wind speed in bin i	m/s
V_{cup}	cup wind speed	
v_{RSD}	wind speed based on remote sensing device measurements	m/s
$v_{\text{reference}}$	wind speed based on reference sensor measurement	m/s
$v_{\text{reference}}$	wind speed measured by the reference wind speed sensor	m/s
$v_{\text{RSD,mh},i}$	wind speed of the RSD at control mast height in bin i	
$v_{\text{MM},i}$	wind speed of the control mast in bin i	
$\overline{V}_{\text{RSD},i}$	bin average of RSD at calibration test in bin i	m/s
$\overline{V}_{\text{Ref},i}$	bin average of reference measurement at calibration test in bin i	m/s
x_{centre}	centre of range covered by x_{SMC} and by the verification test $x_{\text{verification\_test}}$	
$x_{\text{max},j,i}$	expected upper range limit of not measured environmental variable j in wind speed bin i	
$x_{\text{min},j,i}$	expected lower range limit of not measured environmental variable j in wind speed bin i	
x_{range}	maximum range of the environmental variable x between the SMC and the verification test (i.e. maximum of ranges of x_{SMC} and $x_{\text{verification\_test}}$)	
x_{SMC}	environmental variable considered in the RSD classification and measured during the SMC	
$x_{\text{verification\_test}}$	environmental variable considered in the RSD classification and measured during the SMC	
$x_{\text{SMC},j,i}$	mean value of the environmental variable j in wind speed bin i as present during the specific measurement campaign	
$\overline{x}_{\text{ver},j,i}$	mean value of the environmental variable j in wind speed bin i as present during the calibration test of the remote sensing device	
α_1	upflow angle into the probe volume	
α_2	upflow angle out of the probe volume	
Φ	opening angle of the RSD from the vertical	
$\sigma(d_i)$	standard deviation of the percentage wind speed deviations of the 10 min data in bin i	

5 General

This document defines methods and requirements for carrying out wind measurements using ground-mounted remote sensing devices (sodars and lidars). Requirements for calibration, classification and mounting are described. Wind measurements carried out in accordance with this document are useable for many purposes in the field of wind energy (e.g. power performance measurement, site assessment, load measurement, noise measurement). The specific standard relating to the intended use case of the wind speed measurements should be referred to for limitations and additional requirements (e.g. height of measurement relative to turbine hub height in the case of power performance measurements). For wind measurements carried out using cup or sonic anemometers mounted on a meteorological mast or turbine nacelle, refer to IEC 61400-50-1. Interfaces between this document and other standards are summarized in Table 1 and Table 2.

Table 1 – Interfaces from other standards to IEC 61400-50-2

Interface description	Reference to other standard	Reference to IEC 61400-50-2	Short use description	Format
Mounting of sensors on meteorological masts	IEC 61400-50-1	Subclause 6.1	Mounting of reference sensors on meteorological masts for RSD calibration and classification	
Assessment of obstacles and terrain	IEC 61400-12-5	Subclause 6.2	Filtering the dataset	From [deg] to [deg]
Side-mounted instruments on meteorological masts	IEC 61400-50-1:2022, Subclause 10.4	Subclause 6.2	Assessing the influence of meteorological mast wake on the RSD measurement	
Assessment of sectors free of meteorological mast wake	IEC 61400-50-1:2022, Subclause 9.3	Subclause 6.2		
Uncertainty of side-mounted instruments on meteorological masts	IEC 61400-50-1:2022, Clause 11	Subclause 6.2	Estimating additional uncertainty due to correction of meteorological mast effect on reference sensor in RSD calibration and classification	
Classification of mast-mounted wind sensors	IEC 61400-50-1:2022, Clause 6	Subclause 6.3		
Mounting of sensors on meteorological masts	IEC 61400-50-1	Clause 7	Mounting of reference sensors on meteorological masts for RSD calibration and classification	
Post-calibration or in-situ calibration of wind sensors	IEC 61400-50-1:2022, Subclause 11.3.3	Clause 7 Subclause 9.4	Application of RSD post-calibration or in-situ calibration	
Calibration of mast-mounted sensors	IEC 61400-50-1:2022, Clause 11	Subclause 8.1	Estimating uncertainty of reference sensors in RSD calibration	

Table 2 – Interfaces from IEC 61400-50-2 to other standards

Interface description	Reference to IEC 61400-50-2	Reference to other standard	Short use description	Format
Definition of RSD measurement heights for a power curve measurement	Subclause 6.1 Subclause 9.1 Clause 10	IEC 61400-12-1	Definition of RSD measurement heights for classification, hub height, REWS and/or shear measurement for a power curve measurement	Heights in metres [m]

When compared to measurements from a meteorological mast-mounted cup anemometer, remote sensing device (RSD) measurements typically display some degree of scatter. Some of this scatter arises due to the sensitivity of the RSD to various environmental conditions (e.g. temperature and wind shear). It is the task of the classification test (Clause 6) to identify and quantify these sensitivities for a number of discrete heights covering the measuring range of interest. As for cup anemometers it is assumed that these sensitivities will be type specific and the classification test needs to be performed for each type of RSD for a minimum of two instruments of each type and at a minimum of two locations.

The remaining scatter in the cup anemometer comparison is considered to be random noise. This arises from a variety of sources. For example, the turbulent de-correlation in the wind due to the distance between the measurement locations leads to scatter. Also, the distance between the individual probe volumes of the remote sensor itself could contribute to such scatter. The random noise is assumed to be unit and site specific, i.e. it can vary between different evaluations of the same RSD.

Depending on the specific use case (e.g. resource assessment, power performance test, etc), a particular unit of an RSD could require a verification test (Clause 7) before being deployed for the specific measurement campaign (SMC). In some situations, it may alternatively be possible to perform the verification test during the SMC (e.g. during the power performance test). This test is a comparison of the RSD measurements to those from calibrated cup anemometers mounted on a meteorological mast spanning a significant portion of the height range of interest. The purpose of this test is to convey traceability to international standards to this particular device, in the form of an uncertainty. Usually the SMC using the RSD will take place at a different location and at a different time and therefore with a different distribution of environmental conditions than for the RSD verification test. Depending on the sensitivities identified during the classification test, the different environmental conditions will alter the performance of the RSD, increasing the uncertainty in relation to that determined in the verification test. Expressions for the uncertainty of the RSD are given in Clause 8.

Clause 9 describes how the cup anemometer measurements from a short meteorological mast can be used to monitor the performance of the RSD. By ensuring at least one common measuring height, it is possible to assess whether the uncertainty obtained in the classification and the verification test is consistent with the performance of the RSD during the SMC. If inconsistencies are identified from this monitoring, the corresponding uncertainties used in the SMC are increased. This provides a useful "safety net" for the methodology and a feedback mechanism that should promote realistic uncertainty assessments.

Reporting requirements for the complete methodology are given in Clause 11.

6 Classification of RSDs

6.1 General

The accuracy of the RSD can be influenced by meteorological variables. As the meteorological conditions during the SMC can be different from those prevailing during the RSD performance verification test, such influences are linked to additional uncertainty. It is therefore necessary to investigate the sensitivity of the performance of the RSD to meteorological variables. The results of such tests shall identify the variables that influence the performance of the RSD and determine the classification of the instrument.

The simplest of these evaluations entails considering the difference between the RSD measurement and a reference measurement as a function of one meteorological variable at a time. An accuracy class of the RSD shall be evaluated for certain ranges of various environmental variables similar to the classification of cup anemometers in accordance with IEC 61400-50-1, based on the empirical analysis of the sensitivities observed during classification tests. Care should be taken to allow for the possible interdependency of environmental variables (e.g. wind shear and turbulence intensity) so that sensitivities are not inadvertently double counted. The uncertainties arising due to RSD classification can then be evaluated.

A case-specific accuracy class may also be evaluated based on the sensitivities of the remote sensing system and the variation of the environmental variables observed during the RSD performance verification and SMC. It should be clearly stated whether a classification result has been derived generically on multiple units or whether it is based on a case-specific evaluation.