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IEC 61400-12-6

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INTERNATIONAL STANDARD

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Wind energy generation systems – Part 12-6: Measurement based nacelle transfer function of electricity producing wind turbines

Systèmes de génération d'énergie éolienne – Partie 12-6: Fonction de transfert de la nacelle fondée sur le mesurage des éoliennes de production d'électricité

IEC 61400-12-6:2022-08(en-fr)

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WIND ENERGY GENERATION SYSTEMS –

Part 12-6: Measurement based nacelle transfer function of electricity producing wind turbines

FOREWORD

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IEC 61400-12-6 has been prepared by IEC technical committee 88: Wind energy generation systems. It is an International Standard.

This first edition of IEC 61400-12-6 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
88/826/CDV	88/871/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.

IMPORTANT – The "colour inside" logo on the cover page of this document 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

The IEC 61400-12 series consists of the following parts, under the general title Wind energy generation systems:

IEC 61400-12:	*Power performance measurements of electricity producing wind turbines – Overview*
IEC 61400-12-1:	*Power performance measurement of electricity producing wind turbines*
IEC 61400-12-2:	*Power performance of electricity producing wind turbines based on nacelle anemometry*
IEC 61400-12-3:	*Power performance – Measurement based site calibration*
IEC 61400-12-4:	*Numerical site calibration*
IEC 61400-12-5:	*Power performance – Assessment of obstacles and terrain*
IEC 61400-12-6:	*Measurement based nacelle transfer function of electricity producing wind turbines*

The purpose of this document is to provide a uniform methodology of measurement, analysis, and reporting for the determination of a nacelle transfer function of electricity producing wind turbines utilising nacelle-anemometry methods. This document is intended to be applied only to horizontal axis wind turbines of sufficient size that the nacelle-mounted anemometer does not significantly affect the flow through the turbine's rotor and around the nacelle and hence does not affect the wind turbine's performance. The intent of this document is that the methods presented herein be utilised when applying the methodology described in IEC 61400-12-2 to determine the power performance of individual wind turbines. This will ensure that the results are as consistent, accurate, and reproducible as possible within the current state of the art for instrumentation and measurement techniques.

This procedure describes how to characterise a wind turbine's nacelle transfer function in terms of wind speeds measured on a meteorological mast as well as a wind speed measured on the hub or nacelle of a wind turbine. The anemometer that is placed on the turbine is measuring a wind speed that is strongly affected by the test turbine's rotor. This procedure includes methods for determining and applying appropriate corrections for this interference. Such a correction is termed a nacelle transfer function which relates the wind speed measured on the turbine to a free-stream wind speed as measured on a meteorological mast. The procedure also provides guidance on determination of measurement uncertainty including assessment of uncertainty sources and recommendations for combining them into uncertainties.

Even when anemometers are carefully calibrated in a quality wind tunnel, fluctuations in magnitude and direction of the wind vector can cause different anemometers to perform differently in the field. Further, the flow conditions close to a turbine nacelle are complex and variable. Therefore, special care should be taken in the selection and installation of the anemometer. These issues are addressed in this document.

This document will benefit those parties interested in power performance testing of wind turbines using IEC 61400-12-2 as well as parties involved in the installation, planning and execution of such tests. When and where appropriate, 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 environmental concerns. 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 intensity, and from the chosen criteria for data selection. Therefore, a user should consider the influence of these differences and the data selection criteria in relation to the purpose of the test before engaging in nacelle transfer function measurements.

WIND ENERGY GENERATION SYSTEMS –

Part 12-6: Measurement based nacelle transfer function of electricity producing wind turbines

1 Scope

This part of IEC 61400-12 specifies a procedure for measuring the nacelle transfer function of a single electricity-producing, horizontal axis wind turbine, which is not considered to be a small wind turbine in accordance with IEC 61400-2. It is expected that this document be used when a valid nacelle transfer function is needed to execute a power performance measurement according to IEC 61400-12-2.

A wind speed measured on the nacelle or hub of a wind turbine is affected by the turbine rotor (i.e. speeded up or slowed down wind speed). In IEC 61400-12-1, an anemometer is located on a meteorological tower that is located between two and four rotor diameters upwind of the test turbine. This location allows direct measurement of the "free" wind with minimum interference from the test turbine's rotor. In the procedure of this document, the anemometer is located on or near the test turbine's nacelle. In this location, the anemometer is measuring a wind speed that is strongly affected by the test turbine's rotor and the nacelle. The procedure in this document includes methods for determining and applying appropriate corrections for this interference. However, note that these corrections inherently increase the measurement uncertainty compared to a properly configured test conducted in accordance with IEC 61400-12-1.

This document specifies how to characterise a wind turbine's nacelle transfer function. The nacelle transfer function is determined by collecting simultaneous measurements of nacelle-measured wind speed and free stream wind speed (as measured on a meteorological mast) for a period that is long enough to establish a statistically significant database over a range of wind speeds and under varying wind and atmospheric conditions. The procedure also provides guidance on determination of measurement uncertainty including assessment of uncertainty sources and recommendations for combining them.

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 60688, *Electrical measuring transducers for converting AC and DC electrical quantities to analogue or digital signals*

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

IEC 61400-12-2:2022, *Wind energy generation systems – Part 12-2: Power performance of electricity producing wind turbines based on nacelle anemometry*

IEC 61400-12-3, *Wind energy generation systems – Part 12-3: Power performance – Measurement based site calibration*

IEC 61400-12-5:2022, *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
complex terrain
terrain surrounding the test site that features significant variations in topography and terrain obstacles that may cause flow distortion

3.3
data set
collection of data sampled over a contiguous period

3.4
documentation
any information regarding the test which is kept in files or data, or both, but which is not necessarily presented in the final report

3.5
flow distortion
change in air flow caused by obstacles, topographical variations, turbine's rotor, turbine's nacelle or other wind turbines that results in a significant deviation of the measured wind speed from the free stream wind speed

3.6
free stream wind speed
horizontal wind speed measured upstream of the rotor of the wind turbine generator that is unaffected by rotor aerodynamics

3.7
turbulence intensity
ratio of the wind speed standard deviation to the mean wind speed, determined from the same set of measured data samples of horizontal wind speed, and taken over a specific period of time

3.8
hub height
<wind turbine> height of the centre of the swept area of the wind turbine rotor above the ground level at the tower base

3.9
measurement period
period during which a statistically significant database has been collected for the power performance test

3.10
measurement sector
sector of wind directions from which data are selected for the measured power curve or during the determination of the nacelle transfer function

3.11
measurement uncertainty
parameter, associated with the result of a measurement, which characterises the dispersion of the values that could reasonably be attributed to the measurand

3.12
method of bins
data reduction procedure that groups test data for a certain parameter into intervals (bins)

Note 1 to entry: The method of bins is normally used for wind speed bins but is also applicable to other parameters.

Note 2 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.

3.13
nacelle
housing which contains the drive train and other elements on top of a horizontal axis wind turbine generator

3.14
NPC
nacelle power curve
measured power performance of a wind turbine expressed as net active electric power output from the wind turbine as a function of free stream wind speed

Note 1 to entry: For the NPC, the free stream wind speed is not directly measured, but rather the nacelle wind speed is measured and a nacelle transfer function is applied to arrive at the free stream wind speed.

3.15
nacelle wind speed
horizontal wind speed measured on top of or in front of the nacelle of a wind turbine

3.16
obstacle
object that blocks the wind and distorts the flow, such as a building or tree

3.17
pitch angle
angle between the chord line at a defined blade radial location (usually 100 % of the blade radius) and the rotor plane of rotation

3.18
report
any information regarding the test which is stated in the final report

3.19
roughness length
extrapolated height at which the mean wind speed becomes zero if the vertical wind profile is assumed to have a logarithmic variation with height

3.20
ruggedness index
RIX_{xx}
measure of terrain, the ruggedness index of which is calculated as the percentage of altitude differences within a given direction sector that exceed an altitude difference of xx × (D + H)

3.21
site calibration
procedure that quantifies and potentially reduces the effects of terrain and obstacles by measuring the correlation over wind direction between the wind speed measured at a reference meteorological mast and the wind speed measured at the wind turbine position

3.22
standard uncertainty
uncertainty of the result of a measurement expressed as a standard deviation

3.23
swept area
for a horizontal-axis turbine, the projected area of the moving rotor upon a plane normal to axis of rotation

Note 1 to entry: For teetering rotors, it should be assumed that the rotor remains normal to the low-speed shaft.

3.24
test site
location of the wind turbine under test and its surroundings

3.25
turbine online
status of the wind turbine, during normal operation excluding cut-in or cut-out, but including any operation at rotor speed in normal operating range where the turbine briefly disconnects from the grid, e.g. switching between generators, generator stages, star/delta or similar

3.26
wind shear
variation of wind speed across a plane perpendicular to the wind direction

4 Symbols, units and abbreviated terms

Symbol or abbreviated term	Description	Unit
A	swept area of the wind turbine rotor	[m^2]
AEP	annual energy production	
ASL	above sea level	[m]
B	barometric pressure	[Pa]
B_{10min}	measured air pressure averaged over 10 minutes	[Pa]
c	sensitivity factor on a parameter (the partial differential)	
$c_{B,i}$	sensitivity factor of air pressure in bin i	[W/Pa]
$c_{d,i}$	sensitivity factor of data acquisition system in bin i	
$c_{k,i}$	sensitivity factor of component k in bin i	
$c_{l,j}$	sensitivity factor of component l in bin j	
$c_{m,i}$	sensitivity factor of air density correction in bin i	[W/m^{3}kg]

Symbol or abbreviated term	Description	Unit
$c_{m,k,i}$	sensitivity factor of component k in bin i on turbine m	
$c_{T,i}$	sensitivity factor of air temperature in bin i	[W/K]]
$c_{V,i}$	sensitivity factor of wind speed in bin i	[W / ms^{-1}]
D	rotor diameter	[m]
D_e	equivalent rotor diameter	[m]
D_n	rotor diameter of neighbouring and operating wind turbine	[m]
D_r	blade rotor diameter	[m]
Elevation	elevation above sea level	[m]
$F(V)$	the Rayleigh cumulative probability distribution function for wind speed	
fi	relative occurrence of wind speed between V_i − 1 and V_i ($F(V_i) - F(V_i - 1)$) within bin i	
H	hub height of wind turbine	[m]
K	von Karman constant, 0,4	
NT	number of turbines	
L	distance between turbine and met mast (2,5D) in terms of rotor diameters	
Lx	contribution factor related to source x	
M	number of uncertainty components in each bin	
M_A	number of category A uncertainty components	
M_B	number of category B uncertainty components	
N	number of bins	
N_h	number of hours in one year ≈ 8 760	
N_i	number of 10-min data sets in wind speed bin i	
N_j	number of 10-min data sets in wind direction bin j	
N_k	is the number of 10-min data sets in bin k	
N_m	number of bins on turbine m	
N_n	number of bins on turbine n	
n_Test	number of turbines tested	
N	velocity profile exponent (n = 0,14)	
NPC	nacelle power curve	
NTF	nacelle transfer function	
P_i	normalised and averaged power output in bin i	[W]
P_n	normalised power output	[W]
$P_{n,i,j}$	normalised power output of data set j in bin i	[W]
P_10min	measured power averaged over 10 min	[W]
P_w	water vapour pressure	[Pa]
R_0	gas constant (= 287,05)	[J/(kg × K)]
R_w	gas constant of water vapour (= 461,5)	[J/(kg × K)]
RIX_{20}	percentage of calculated slopes within a given direction sector that exceed 20 %	
$s_{sc,i}$	standard deviation of the wind speed ratios in bin i	
S	uncertainty component of category A	[W]

Symbol or abbreviated term	Description	Unit
$s_{k,i}$	category A standard uncertainty of component k in bin i	[W]
s_i	combined category A uncertainties in bin i	[W]
$s_{P,i}$	category A standard uncertainty of power in bin i	[W]
$s_{\mathrm{NTF},i}$	statistical uncertainty in captured dataset	
$s_{\alpha,j}$	category A standard uncertainty of wind speed ratios in bin j	[W]
Slope_i	slope between adjacent elevation points	[°]
T	absolute temperature	[K]
TI	turbulence intensity	
T_{10min}	measured absolute air temperature averaged over 10 min	[K]
T	time	[s]
U	uncertainty component of category B	
U_i	Combined category B uncertainties in bin i	
u_{AEP}	combined standard uncertainty in the estimated annual energy production	[Wh]
$u_{\mathrm{AEP,AVG}}$	uncertainty in the average AEP	[Wh]
$u_{\mathrm{AEP},k}$	uncertainty in AEP from category B component k	[Wh]
$u_{\mathrm{AEP},m,k}$	uncertainty in AEP from category B component k on turbine m	[Wh]
u_{AEPRATIO}	ratio of the uncertainty in the AEP	[Wh]
$u_{\mathrm{ano\_class}}$	uncertainty related to anemometer class	[W]
$u_{B,i}$	category B standard uncertainty of air pressure in bin i	[W]
$u_{c,i}$	combined standard uncertainty of the power in bin i	[W]
$u_{c,m,i}$	combined uncertainty in power in bin i on turbine m	[W]
$u_{\mathrm{dFS},i}$	uncertainty component for data acquisition system	
$u_{\mathrm{dP},i}$	uncertainty component for data acquisition of power in bin i	
$u_{\mathrm{dT},i}$	uncertainty component for data acquisition of temperature in bin i	
$u_{\mathrm{d}V,i}$	uncertainty component for data acquisition of wind speed in bin i	
$u_{\mathrm{dWD},i}$	uncertainty component for data acquisition of wind direction in bin i	
u_{FS}	uncertainty component for free stream wind speed	[W]
U_i	combined category B uncertainties in bin i	
$u_{k,i}$	category B standard uncertainty of component k in bin i	[W]
$u_{m,k,i}$	standard uncertainty of component k in bin i on turbine m	[W][kg/m^3]
$u_{l,j}$	standard uncertainty of component l in bin j	[W]
$u_{m,i}$	category B standard uncertainty of air density correction in bin i	[kg/m^3]
u_N	uncertainty component for nacelle wind speed	
$u_{P,i}$	category B standard uncertainty of power in bin i	[W]
u_{sc}	category B standard uncertainty of power in bin i	[W]
$u_{\mathrm{sc},i,j}$	uncertainty component for site calibration in wind speed bin i and wind direction bin j	[W]
$u_{T,i}$	category B standard uncertainty of air temperature in bin i	[K]
$u_{V,i}$	category B standard uncertainty of wind speed in bin i	[W]