IEC 61400-12-2

Edition 1.0 2013-03

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Wind turbines –
Part 12-2: Power performance of electricity-producing wind turbines based on nacelle anemometry

Eoliennes –
Partie 12-2: Performance de puissance des éoliennes de production d'électricité basée sur l'anémométrie de nacelle

IEC 61400-12-2:2013

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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International Standard IEC 61400-12-2 has been prepared by IEC technical committee 88: Wind turbines.

The text of this standard is based on the following documents:

FDIS	Report on voting
88/442/FDIS	88/445/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The contents of the corrigendum of September 2016 have been included in this copy.

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 publication using a colour printer.

INTRODUCTION

The purpose of this part of IEC 61400-12 is to provide a uniform methodology of measurement, analysis, and reporting of power performance characteristics for individual electricity-producing wind turbines utilising nacelle-anemometry methods. This standard 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 standard is that the methods presented herein be utilised when the requirements set forth in IEC 61400-12-1:2005 are not feasible. 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 power performance characteristics in terms of a measured power curve and the estimated annual energy production (AEP) based on nacelle-anemometry. In this procedure, the anemometer is located on or near the test turbine's nacelle. In this location, the anemometer is measuring 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. However, it must be noted that these corrections inherently increase the measurement uncertainty compared to a properly-configured test conducted in accordance with IEC 61400-12-1:2005. The procedure also provides guidance on determination of measurement uncertainty including assessment of uncertainty sources and recommendations for combining them into uncertainties in reported power and AEP.

A key element of power performance testing is the measurement of wind speed. 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 standard.

The standard will benefit those parties involved in the manufacture, installation, planning and permitting, operation, utilisation and regulation of wind turbines. When appropriate, the technically accurate measurement and analysis techniques recommended in this standard 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 standard presents measurement and reporting procedures expected to provide accurate results that can be replicated by others.

Meanwhile, a user of the standard 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 contracting power performance measurements.

WIND TURBINES –

Part 12-2: Power performance of electricity-producing wind turbines based on nacelle anemometry

1 Scope

This part of IEC 61400-12 specifies a procedure for verifying the power performance characteristics of a single electricity-producing, horizontal axis wind turbine, which is not considered to be a small wind turbine per IEC 61400-2. It is expected that this standard will be used when the specific operational or contractual specifications may not comply with the requirements set forth in IEC 61400-12-1:2005. The procedure can be used for power performance evaluation of specific turbines at specific locations, but equally the methodology can be used to make generic comparisons between different turbine models or different turbine settings.

The wind turbine power performance characterised by the measured power curve and the estimated AEP based on nacelle-measured wind speed will be affected by the turbine rotor (i.e. speeded up or slowed down wind speed). The nacelle-measured wind speed shall be corrected for this flow distortion effect. Procedures for determining that correction will be included in the methodology. In IEC 61400-12-1:2005, 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 this IEC 61400-12-2 procedure, the anemometer is located on or near the test turbine's nacelle. In this location, the anemometer is measuring wind speed that is strongly affected by the test turbine's rotor and the nacelle. This procedure includes methods for determining and applying appropriate corrections for this interference. However, it should be noted that these corrections inherently increase the measurement uncertainty compared to a properly-configured test conducted in accordance with IEC 61400-12-1:2005.

This IEC 61400-12-2 standard describes how to characterise a wind turbine's power performance in terms of a measured power curve and the estimated AEP. The measured power curve is determined by collecting simultaneous measurements of nacelle-measured wind speed and power output 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. In order to accurately measure the power curve, the nacelle-measured wind speed is adjusted using a transfer function to estimate the free stream wind speed. The procedure to measure and validate such a transfer function is presented herein. The AEP is calculated by applying the measured power curve to the reference wind speed frequency distributions, assuming 100 % availability. The procedure also provides guidance on determination of measurement uncertainty including assessment of uncertainty sources and recommendations for combining them into uncertainties in reported power and AEP.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC/TR 60688, *Electrical measuring transducers for converting a.c. electrical quantities to analogue or digital signals*
Amendment 1 (1997)
Amendment 2 (2001)

IEC 61400-12-1:2005, *Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines*

IEC 61869-2, *Instrument transformers – Part 2: Additional requirements for current transformers*

IEC 61869-3, *Instrument transformers – Part 3: Additional requirements for inductive voltage transformers*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

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

ISO 2533, *Standard atmosphere*

3 Terms and definitions

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

3.1
accuracy
closeness of the agreement between the result of a measurement and a true value of the measurand

3.2
annual energy production (AEP)
estimate of the total energy production of a wind turbine during a one-year period by applying the measured power curve to different reference wind speed frequency distributions at hub height, assuming 100 % availability

3.3
annual energy production – measured (AEP-measured)
estimate of the total energy production of a wind turbine during a one-year period by applying the measured power curve to different reference wind speed frequency distributions at hub height, assuming 100 % availability, without power curve extrapolation to higher wind speeds

3.4
annual energy production – extrapolated (AEP-extrapolated)
estimate of the total energy production of a wind turbine during a one-year period by applying the measured power curve to different reference wind speed frequency distributions at hub height, assuming 100 % availability, with power curve extrapolation to cut-out wind speed of the turbine

3.5
complex terrain
terrain surrounding the test site that features significant variations in topography and terrain obstacles that may cause flow distortion

3.6
data set
collection of data that was sampled over a contiguous period

3.7
documentation
any information regarding the test which is kept in files and/or data, but which may not necessarily be presented in the final report

3.8
extrapolated power curve
extension of the measured power curve by estimating power output from the maximum measured wind speed to cut-out wind speed

3.9
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

3.10
free stream wind speed
horizontal wind speed measured upstream of the rotor of the wind turbine generator that is unaffected by rotor aerodynamics

3.11
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

3.12
hub height (wind turbines)
height of the centre of the swept area of the wind turbine rotor above the ground level at the tower base

3.13
machine configuration change
a change to the turbine or intervention in the turbine operation which causes a significant change in the power performance of the turbine and which is not normal maintenance

EXAMPLE Replacements of hardware components, especially rotor blade, gearbox or generator; a change or update of the turbine software or its parameters, unplanned blade washing.

3.14
measured power curve
table and graph that represents the measured, corrected and normalised net power output of a wind turbine as a function of measured free stream wind speed, measured under a well-defined measurement procedure

3.15
measurement period
period during which a statistically significant database has been collected for the power performance test

3.16
measurement sector
a sector of wind directions from which data are selected for the measured power curve or during the determination of the nacelle transfer function

3.17
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

3.18
method of bins
data reduction procedure that groups test data for a certain parameter into intervals (bins). Normally used for wind speed bins but also applicable to other parameters.

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.

3.19
nacelle
housing which contains the drive train and other elements on top of a horizontal axis wind turbine generator

3.20
nacelle power curve (NPC)
the 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; 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

3.21
nacelle wind speed
horizontal wind speed measured on top of or in front of the nacelle of a wind turbine

3.22
net active electric power
measure of the wind turbine electric power output that is delivered to the electrical power network

3.23
normal maintenance
any intervention which is done according to a defined regular maintenance program, independent from the fact that a power performance test is being done, e.g. oil change, blade washing (if due anyway, independent from the power performance test)

3.24
obstacles
objects that block the wind and create distortion of the flow, such as buildings and trees

3.25
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

3.26
power coefficient
ratio of the net electric power output of a wind turbine to the power available in the free stream wind over the rotor swept area

3.27
power performance
measure of the capability of a wind turbine to produce electric power and energy

3.28
rated power
quantity of power assigned, generally by a manufacturer, for a specified operating condition of a component, device or equipment

3.29
report
any information regarding the test which is stated in the final report

3.30
roughness length
extrapolated height at which the mean speed becomes zero if the vertical wind profile is assumed to have a logarithmic variation with height

3.31
ruggedness index
RIX_{xx}
a measure of terrain, the ruggedness index is calculated as the percentage of altitude differences within a given direction sector that exceed an altitude difference of xx × (D+H)

3.32
site calibration
a 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

3.33
standard uncertainty
uncertainty of the result of a measurement expressed as a standard deviation

3.34
swept area
for a horizontal-axis turbine, the projected area of the moving rotor upon a plane normal to axis of rotation; for teetering rotors, it should be assumed that the rotor remains normal to the low-speed shaft

3.35
test site
location of the wind turbine under test and its surroundings

3.36
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

3.37
wind shear
variation of wind speed across a plane perpendicular to the wind direction

4 Symbols and units

Symbol	Description	Unit
A	swept area of the wind turbine rotor	[m^2]
AEP	annual energy production	[Wh]
AEP_m	the measured AEP on turbine m	[Wh]
AEP_s	Sum of annual energy production	[Wh]
ASL	Above Sea Level	[m]
B	barometric pressure	[Pa]
B_{10min}	measured air pressure averaged over 10 minutes	[Pa]
C_p	power coefficient	
$C_{p,i}$	power coefficient in bin i	
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]
$c_{m,k,i}$	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 root diameter	[m]
Δz_i	Vertical distance between adjacent elevation points	[m]
$elevation$	elevation above sea level	[m]
$F(V)$	the Rayleigh cumulative probability distribution function for wind speed	
H	hub height of wind turbine	[m]
h	height of obstacle minus zero displacement	[m]
K	von Karman constant, 0,4	
NT	number of turbines	
L	distance between the turbine and met mast (2,5D) in terms of rotor diameters	
Le	distance between the wind turbine or the meteorological mast and an obstacle	[m]
Ln	actual distance between neighbouring and operating wind turbine or the meteorological mast and a neighbouring and operating wind turbine	[m]
Lh	actual height of obstacle	[m]
Lw	distance between the wind turbine or the meteorological mast and a neighbouring and operating wind turbine	[m]
M	number of uncertainty components in each bin	