# IEC 61400-12

Edition 1.0 2022-09

# INTERNATIONAL STANDARD

# NORME INTERNATIONALE

colour inside



**Wind energy generation systems –
Part 12: Power performance measurements of electricity producing wind turbines – Overview**

**Systèmes de génération d'énergie éolienne –
Partie 12: Mesurages de performance de puissance des éoliennes de production d'électricité – Vue d'ensemble**

IEC 61400-12:2022-09(en-fr)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

**IEC 61400-12**

Edition 1.0 2022-09

# INTERNATIONAL STANDARD

# NORME INTERNATIONALE

colour inside



## Wind energy generation systems –
## Part 12: Power performance measurements of electricity producing wind turbines – Overview

## Systèmes de génération d'énergie éolienne –
## Partie 12: Mesurages de performance de puissance des éoliennes de production d'électricité – Vue d'ensemble

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 27.180

ISBN 978-2-8322-5620-6

**Warning! Make sure that you obtained this publication from an authorized distributor.**
**Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.**

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

---

**WIND ENERGY GENERATION SYSTEMS –**

**Part 12: Power performance measurements of electricity producing wind turbines – Overview**

## FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.



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

This first edition of IEC 61400-12 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 |
|---|---|
| 88/830/CDV | 88/866/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 comprises a sub-set of standards which are for use in the evaluation and measurement of the power performance characteristics of wind turbines. The power performance characterization of wind turbines of all types and sizes is covered.

IEC TC 88 has made this revision to reduce the complexity and to improve the maintainability of the previous version. Wind measurement procedures have been extracted from the performance standard, recognizing that wind measurements need to be referenced from other standards, such as in loads, noise and resource assessment measurements. IEC TC 88 recommends that the restructured standards gradually take over the previous standards before Maintenance Cycle Reports are written on the restructured standards introducing new technical requirements. Revision of the restructured documents should be proposed at the same time to incorporate such technical changes, recommendations, clarifications and simplifications.

The purpose of the IEC 61400-12 series is to provide a uniform methodology that will ensure consistency, accuracy and reproducibility in the measurement and analysis of power performance by wind turbines. These International Standards have been prepared with the anticipation that they 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 can 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 needs 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.



The IEC 61400-12 series provides guidance in the measurement, analysis, and reporting of power performance testing for wind turbines. These International Standards 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 these standards 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. These standards present measurement and reporting procedures expected to provide accurate results that can be replicated by others. Meanwhile, a user of these standards should be aware of differences in performance or the measurement of performance that arise from large variations in wind shear and turbulence. Not all of the test methods specified in the IEC 61400-12 series enable quantification of the impact of shear and turbulence. Therefore, a user should consider the influence of these differences, the most appropriate test method/standard and the data selection criteria in relation to the purpose of the test before contracting the power performance measurements.

Procedures for calibration, classification and uncertainty assessment of cup anemometers and ultrasonic anemometers are given in IEC 61400-50-1. Procedures for calibration, classification and uncertainty assessment of remote sensing devices are given in IEC 61400-50-2. Special care should be taken in the selection of the instruments chosen to measure the wind speed because it can influence the result of the power performance test.

# WIND ENERGY GENERATION SYSTEMS –

# Part 12: Power performance measurements of electricity producing wind turbines – Overview

## 1 Scope

This part of IEC 61400 defines procedures for assessing the power performance characteristics of wind turbines.

This document provides a general introduction to the available options for power performance measurement and the contributing evaluations which are further detailed in the other parts of the IEC 61400-12 series. Although this document (along with other parts of the IEC 61400-12 series) also defines the specifications of the meteorological variables (and in particular wind speed) required for the power performance evaluation, the methods and procedures for measuring or otherwise acquiring the wind speed data are defined in the IEC 61400-50 wind measurement series.

## 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 61400-12-2, *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, *Wind energy generation systems – Part 12-5: Power performance – Assessment of obstacles and terrain*

IEC 61400-12-6, *Wind energy generation systems – Part 12-6: Measurement based nacelle transfer function of electricity producing wind turbines*

IEC 61400-50, *Wind energy generation systems – Part 50: Wind measurement – Overview*

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

IEC 61400-50-2, *Wind energy generation systems – Part 50-2: Wind measurement – Application of ground-mounted remote sensing technology*

IEC 61400-50-3, *Wind energy generation systems – Part 50-3: Use of nacelle-mounted lidars for wind measurements*

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

**3.2**
**data set**
collection of data sampled over a continuous period

**3.3**
**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



**3.4**
**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.

**3.5**
**measured power curve**
table and graph that represents 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

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.

**3.6**
**net active electric power**
measure of the wind turbine electric power output that is delivered to the electrical power network

**3.7**
**obstacle**
obstruction that blocks the wind and creates distortion of the flow

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

**3.8**
**power performance**
measure of the capability of a wind turbine to produce electric power and energy

**3.9**
**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

SEE: Equation (3)

**3.10**
**test site**
location of the wind turbine under test and its surroundings

**3.11**
**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

**3.12**
**wind measurement equipment**
meteorological mast or remote sensing device

**3.13**
**wind shear**
change of wind speed with height across the wind turbine rotor

**3.14**
**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 |
|---|---|---|
| $A$ | swept area of the wind turbine rotor | $m^2$ |
| AEP | annual energy production | Wh |
| $P_{\text{kin}}$ | kinetic energy flux | W |
| RSD | remote sensing device | |
| $V$ | wind speed | m/s |
| $V_i$ | wind speed at height $i$ | m/s |
| $v_{\text{eq}}$ | measured equivalent wind speed | m/s |
| WME | wind measurement equipment | |
| $\rho$ | air density | $kg/m^3$ |
| $\Phi$ | relative humidity (range 0 % to 100 %) | |
| $\omega$ | angular speed | $s^{-1}$ |
| $\varphi$ | wind direction | rad |
| $\varphi_{\text{hub}}$ | wind direction at hub height | rad |
| $\varphi_i$ | wind direction at height $i$ | rad |

## 5 Power performance method overview

Wind turbine power performance characteristics are determined from a measured power curve and an associated estimated annual energy production (AEP) and its uncertainty. The measured power curve, defined as the relationship between the wind speed and the wind turbine power output, is determined by collecting simultaneous measurements of meteorological variables (including wind speed), as well as wind turbine signals (including power output) at the test site 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 AEP is calculated by applying the measured power curve to reference wind speed frequency distributions, assuming 100 % availability.

The power performance measurement method used in the IEC 61400-12 series is based on a definition of the power curve that expresses power produced versus the wind speed that represents effectively the kinetic energy flux in the wind flowing across the swept area of the rotor.

The kinetic energy flux (referring to a certain point in time or period of time, typically 10 min, assuming that the wind speed does not change within this time across the vertical capture area is in general terms expressed as:

$$P_{\text{kin}} = \int_A \frac{1}{2} \rho V^3 \mathrm{d}A \qquad (1)$$



Here the wind speed $V$, measured at a point in space over the rotor area, is the horizontal wind speed.



NOTE 1 Wind turbine power seems to correlate better with the horizontal wind speed definition than with a vector wind speed definition for a one-point hub height wind speed measurement.



NOTE 2 If the wind speed changes (i.e. if the turbulence intensity is greater than zero) during a certain time period, then the kinetic power (averaged over this time period) is higher than in the case of a constant wind speed, whereas a wind turbine has only a limited possibility to transform this additional kinetic power into additional electric power. This issue is not taken into further consideration in this document. As a simplification, Equations (1), (2), (3) are considered valid here, even in the case of a turbulence intensity greater than zero. The impact of wind speed changes on the time averaged kinetic power and the associated impact on the wind turbine power curve are treated by the turbulence normalization procedure as included in IEC 61400-12-1.

The horizontal wind speed is defined as the average magnitude of the horizontal component of the instantaneous wind velocity vector, including only the longitudinal and lateral (but not the vertical) components. When we consider a horizontal axis wind turbine the wind veer is also taken into account and the kinetic energy in the wind is corrected according to the wind direction at hub height:

$$P_{\text{kin}} = \int_A \frac{1}{2} \rho (V \cos(\varphi - \varphi_{\text{hub}}))^3 \mathrm{d}A \qquad (2)$$

Here $\varphi_{\text{hub}}$ is the wind direction at hub height. The wind veer can vary significantly over the rotor height of large wind turbines for extreme atmospheric stability conditions and it is also dependent on topography at the site.

In this document we do not consider wind shear and wind veer in the horizontal plane. Thus, the energy equivalent wind speed that corresponds to the kinetic energy in the wind as derived from the expression of kinetic energy in Equation (2) in general is described as:

$$V_{\text{eq}} = \left(\frac{1}{A}\int_i (V_i \cos(\varphi_i - \varphi_{\text{hub}}))^3 \mathrm{d}A_i\right)^{1/3} \tag{3}$$

In this document, the index $i$ refers to the height within the rotor area.

NOTE 3 When wind speed is mentioned in this document, it is by default referring to the hub height wind speed definition unless specifically stated to be this energy equivalent wind speed definition.

Although horizontal wind speed is considered to be the influential wind speed parameter, on sites with significant non-horizontal flow (upflow or downflow), there is additional uncertainty associated with both the measurement of the horizontal wind speed and the response of the wind turbine.

The wind shear and wind veer can vary significantly over the rotor height of large wind turbines due to atmospheric stability conditions and it is also dependent on topography at the site. The occurrence of extreme atmospheric stability conditions is a site-specific issue, and if occurring during a power performance test the power curve can vary significantly.

At sites with low and homogeneous wind shear and wind veer over the rotor (and for turbines with small rotor diameters in possibly more complex wind flow conditions), the wind speed measured at hub height can be a good representation of the kinetic energy to be captured by the rotor. Hub height wind speed is the wind speed upon which power curves have historically been defined in all previous editions of parts of the IEC 61400-12 series. For that reason, the wind speed measured at hub height is the default definition of wind speed and shall always be measured and reported, even when more comprehensive measurements of wind speed are available over the rotor height.



At sites and seasons where extreme atmospheric stability conditions are expected to be frequent, it is recommended always to measure wind shear. Not all power curve measurement methods can provide measurements of wind shear (e.g. the measurements described in IEC 61400-12-2 cannot provide information on wind shear). Therefore, the choice of power curve measurement methodology can be driven by the site-specific atmospheric stability conditions expected.

If wind shear and wind veer are not measured over the full height of the rotor there is added uncertainty in the rotor equivalent wind speed. This uncertainty in measurement decreases as more wind speed and wind direction measurement heights are used. If measurements are limited to only hub height and there is no measurement of wind shear over the most significant parts of the rotor, then this implies an uncertainty in determination of the rotor equivalent wind speed.

For small wind turbines (refer to IEC 61400-2), where the influence of the wind shear and wind veer are insignificant, the wind speed shall be represented by a hub height wind speed measurement alone without adding uncertainty due to lack of wind shear and wind veer measurements.

For vertical axis wind turbines, where the influence of the wind veer is not present, the wind veer shall be neglected.

As the wind conditions at the position of the test turbine and at the position of the wind measurement can differ significantly if the test turbine and/or the wind measurement is located in the wakes of any wind turbines, such situations shall be excluded from the test. IEC 61400-12-5 shall be used to identify wake-affected situations. Additionally, the wind conditions at the position of the test turbine and at the position of the wind measurement can differ significantly due to the impact of the surrounding terrain, in which case a site calibration