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INTERNATIONAL STANDARD

Wind turbines –
Part 12-1: Power performance measurements of electricity producing wind turbines

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND TURBINES –

Part 12-1: Power performance measurements of electricity producing wind turbines

FOREWORD

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International Standard IEC 61400-12-1 has been prepared by IEC technical committee 88: Wind turbines.

This standard cancels and replaces IEC 61400-12 published in 1998. This first edition of IEC 61400-12-1 constitutes a technical revision. IEC 61400-12-2 and IEC 61400-12-3 are additions to IEC 61400-12-1.

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

FDIS	Report on voting
88/244/FDIS	88/251/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.

IEC 61400-12 consists of the following parts, under the general title *Wind turbines:*

Part 12-1: Power performance measurements of electricity producing wind turbines

Part 12-2: Verification of power performance of individual wind turbines (under consideration)

Part 12-3: Wind farm power performance testing (under consideration)

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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- withdrawn;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.

A bilingual version of this standard may be issued at a later date.

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 power performance by wind turbines. The standard has been prepared with the anticipation that it would be applied by:

– a wind turbine manufacturer striving to meet well-defined power performance requirements and/or a possible declaration system;
– a wind turbine purchaser in specifying such performance requirements;
– a wind turbine operator who may be required to verify that stated, or required, power performance specifications are met for new or refurbished units;
– a wind turbine planner or regulator who must 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 standard provides guidance in the measurement, analysis, and reporting of power performance testing for wind turbines. The standard 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 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, 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 the power performance measurements.

A key element of power performance testing is the measurement of wind speed. This standard prescribes the use of cup anemometers to measure the wind speed. This instrument is robust and has long been regarded as suitable for this kind of test. Even though suitable wind tunnel calibration procedures are adhered to, the field flow conditions associated with the fluctuating wind vector, both in magnitude and direction, will cause different instruments to potentially perform differently.

Tools and procedures to classify cup anemometers are given in Annexes I and J. However there will always be a possibility that the result of the test can be influenced by the selection of the wind speed instrument. Special care should therefore be taken in the selection of the instruments chosen to measure the wind speed.

WIND TURBINES –

Part 12-1: Power performance measurements of electricity producing wind turbines

1 Scope

This part of IEC 61400 specifies a procedure for measuring the power performance characteristics of a single wind turbine and applies to the testing of wind turbines of all types and sizes connected to the electrical power network. In addition, this standard describes a procedure to be used to determine the power performance characteristics of small wind turbines (as defined in IEC 61400-2) when connected to either the electric power network or a battery bank. The procedure can be used for 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 characteristics are determined by the measured power curve and the estimated annual energy production (*AEP*). The measured power curve is determined by collecting simultaneous measurements of wind speed and 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 standard describes a measurement methodology that requires the measured power curve and derived energy production figures to be supplemented by an assessment of uncertainty sources and their combined effects.

2 Normative references

The following referenced documents are indispensable for the application 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 60044-1:1996, *Instrument transformers – Part 1: Current transformers*
Amendment 1 (2000)
Amendment 2 (2002)[1]

IEC 60688:1992, *Electrical measuring transducers for converting a.c. electrical quantities to analogue or digital signals*
Amendment 1 (1997)
Amendment 2 (2001)[2]

IEC 61400-2:1996, *Wind turbine generator systems – Part 1: Safety of small wind turbines*

ISO 2533:1975, *Standard atmosphere*

ISO Guide to the expression of uncertainty in measurement, 1995, ISBN 92-67-10188-9

[1] There exists a consolidated edition 1.2 (2003) that includes edition 1 and its amendments 1 and 2.

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

3.4
data set
collection of data that was sampled over a continuous period

3.5
distance constant
indication of the response time of an anemometer, defined as the length of air that must pass the instrument for it to indicate 63 % of the final value for a step input in wind speed

3.6
extrapolated power curve
extension of the measured power curve by estimating power output from the maximum measured wind speed to cut-out wind speed

3.7
flow distortion
change in air flow caused by obstacles, topographical variations, or other wind turbines that results in a deviation of the measured wind speed from the free stream wind speed and in a significant uncertainty

3.8
hub height (wind turbines)
height of the centre of the swept area of the wind turbine rotor above the ground at the tower

NOTE For a vertical axis wind turbine the hub height is the height of the equator plane.

3.9
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

3.10
measurement period
period during which a statistically significant database has been collected for the power performance test

3.11
measurement sector
a sector of wind directions from which data are selected for the measured power curve

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

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

3.14
obstacles
things that blocks the wind and creates distortion of the flow, such as buildings and trees

3.15
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

3.16
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

3.17
power performance
measure of the capability of a wind turbine to produce electric power and energy

3.18
rated power
quantity of power assigned, generally by a manufacturer, for a specified operating condition of a component, device or equipment

NOTE Maximum continuous electrical power output which a wind turbine is designed to achieve under normal operating conditions.

3.19
standard uncertainty
uncertainty of the result of a measurement expressed as a standard deviation

3.20
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. For a vertical axis turbine, the projected area of the moving rotor upon a vertical plane.

3.21
test site
location of the wind turbine under test and its surroundings

3.22
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

4 Symbols and units

A	swept area of the wind turbine rotor	[m^2]
AEP	annual energy production	[Wh]
B	barometric pressure	[Pa]
B_{10min}	measured air pressure averaged over 10 min	[Pa]
C_h	pitot tube head coefficient	
$C_{P,i}$	power coefficient in bin i	
C_{QA}	generalized aerodynamic torque coefficient	
C_T	thrust coefficient	
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_{index}	sensitivity factor of index parameter	
$c_{k,i}$	sensitivity factor of component k in bin i	
$c_{m,i}$	sensitivity factor of air density correction in bin i	[Wm^3/kg]
$c_{T,i}$	sensitivity factor of air temperature in bin i	[W/K]
$c_{V,i}$	sensitivity factor of wind speed in bin i	[Ws/m]
D	rotor diameter	[m]
D_e	equivalent rotor diameter	[m]
D_n	rotor diameter of neighbouring and operating wind turbine	[m]
d	mast diameter	[m]
$F(V)$	the Rayleigh cumulative probability distribution function for wind speed	
f_i	the relative occurrence of wind speed in a wind speed interval	
H	hub height of wind turbine	[m]
h	height of obstacle minus zero displacement	[m]
I	inertia of cup anemometer rotor	[kgm^2]
k	class number	
k_b	blockage correction factor	
k_c	wind tunnel calibration factor	
k_f	wind tunnel correction factor to other tunnels (only used in uncertainty estimate)	
k_ρ	humidity correction to density	
$K_{B,t}$	barometer	
$K_{B,s}$	barometer gain	
$K_{B,d}$	barometer sampling	
$K_{T,t}$	temperature transducer	
$K_{T,s}$	temperature transducer gain	
$K_{T,d}$	temperature transducer sampling	
$K_{p,t}$	pressure transducer sensitivity	
$K_{p,s}$	pressure transducer gain	
$K_{p,d}$	pressure transducer sampling conversion	

L	leg distance of three legged mast	[m]
L	distance between the wind turbine and the meteorological mast	[m]
L_e	distance between the wind turbine or the meteorological mast and an obstacle [m]	
L_n	distance between the wind turbine or the meteorological mast and a neighbouring and operating wind turbine	[m]
l_h	height of obstacle	[m]
l_w	width of obstacle	[m]
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 ≈ 8760	[h]
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	number of samples within sampling interval	
n	velocity profile exponent (n=0,14)	
P_0	porosity of obstacle (0: solid, 1: no obstacle)	
P_i	normalized and averaged power output in bin i	[W]
P_n	normalized power output	[W]
$P_{n,i,j}$	normalized power output of data set j in bin i	[W]
P_{10min}	measured power averaged over 10 min	[W]
P_w	vapour pressure	[Pa]
Q_A	aerodynamic torque	[Nm]
Q_f	friction torque	[Nm]
R	distance to mast centre	[m]
R_0	gas constant of dry air (287,05)	[J/(kgK)]
R_w	gas constant of water vapour (461,5)	[J/kgK]
r	correlation coefficient	
s	uncertainty component of category A	
s_A	category A standard uncertainty of tunnel wind speed time series	
$s_{k,i}$	category A standard uncertainty of component k in bin i	
s_i	combined category A uncertainties in bin i	
$s_{P,i}$	category A standard uncertainty of power in bin i	[W]
$s_{w,i}$	category A standard uncertainty of climatic variations in bin i	
$s_{\alpha,j}$	category A standard uncertainty of wind speed ratios in bin j	
T	absolute temperature	[K]
TI	turbulence intensity	
T_{10min}	measured absolute air temperature averaged over 10 min	[K]
t	mast solidity	
t	time	[s]
U	wind speed	[m/s]
U_d	centre-line wind speed deficit	[m/s]
U_{eq}	equivalent horizontal wind speed	[m/s]
U_h	free wind speed at height h of obstacle	[m/s]