INTERNATIONAL STANDARD

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Wind turbine generator systems –

Part 12:
Wind turbine power performance testing

Aérogénérateurs –

Partie 12:
Techniques de mesure des performances de puissance

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CONTENTS

Page

Figures

Annexes

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND TURBINE GENERATOR SYSTEMS –

Part 12: Wind turbine power performance testing

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the 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, the IEC publishes International Standards. 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. The 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 the 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 National Committees.
3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical reports or guides and they are accepted by the National Committees in that sense.
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International Standard IEC 61400-12 has been prepared by IEC technical committee 88: Wind turbine generator systems.

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

FDIS	Report on voting
88/85/FDIS	88/89/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.

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

Annexes A and C form an integral part of this standard.

Annexes B, D and E are for information only.

INTRODUCTION

The purpose of this part of IEC 61400 is to provide a uniform methodology that will ensure consistency and accuracy in the measurement and analysis of power performance by wind turbine generator systems (WTGS). The standard has been prepared with the anticipation that it would be applied by:

– the WTGS manufacturer striving to meet well-defined power performance requirements and/or a possible declaration system;
– the WTGS purchaser in specifying such performance requirements;
– the WTGS operator who may be required to verify that stated, or required, power performance specifications are met for new or refurbished units;
– the WTGS planner or regulator who must be able to accurately and fairly define power performance characteristics of WTGS 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 turbine generator systems (WTGS). The standard will benefit those parties involved in the manufacture, installation planning and permitting, operation, utilization, and regulation of WTGS. 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 WTGS 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.

However, readers should be warned that the site calibration procedure is quite new. As yet there is no substantial evidence that it can provide accurate results for all sites, especially sites in complex terrain. Part of the procedure is based on applying uncertainty calculations on the measurements. In complex terrain situations it is not adequate to state that results are accurate since uncertainties might be 10 % to 15 % in standard deviation. A new measurement standard, accounting for these problems, will be developed in future.

WIND TURBINE GENERATOR SYSTEMS –

Part 12: Wind turbine power performance testing

1 General

1.1 Scope

This part of IEC 61400 specifies a procedure for measuring the power performance characteristics of a single wind turbine generator system (WTGS) and applies to the testing of WTGS of all types and sizes connected to the electrical power network. It is applicable for the determination of both the absolute power performance characteristics of a WTGS and of differences between the power performance characteristics of various WTGS configurations.

The WTGS 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 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.

1.2 Normative references

The following normative documents, through reference in this text, constitute provisions of this part of IEC 61400. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this part of IEC 61400 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60044-1:1996, *Instrument transformers – Part 1: Current transformers*

IEC 60186:1987, *Voltage transformers*
Amendment 1 (1988).
Amendment 2 (1995).

IEC 60688:1992, *Electrical measuring transducers for converting a.c. electrical quantities to analogue or digital signals*

ISO 2533:1975, *Standard atmosphere*

Guide to the expression of uncertainty in measurement, ISO information publications, 1995, 110 p. ISBN 92-67-10188-9

1.3 Definitions

For the purposes of this part of IEC 61400, the following definitions apply.

1.3.1
accuracy
closeness of the agreement between the result of a measurement and a true value of the measurand

1.3.2
annual energy production
estimate of the total energy production of a WTGS during a one-year period by applying the measured power curve to different reference wind speed frequency distributions at hub height, assuming 100 % availability

1.3.3
availability
ratio of the total number of hours during a certain period, excluding the number of hours that the WTGS could not be operated due to maintenance or fault situations, to the total number of hours in the period, expressed as a percentage

1.3.4
complex terrain
terrain surrounding the test site that features significant variations in topography and terrain obstacles that may cause flow distortion

1.3.5
data set
collection of data that was sampled over a continuous period

1.3.6
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

1.3.7
extrapolated power curve
extension of the measured power curve by estimating power output from the maximum measured wind speed to cut-out wind speed

1.3.8
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

1.3.9
free stream wind speed
speed of the undisturbed natural air flow, usually at hub height

1.3.10
hub height (wind turbines)
height of the center of the swept area of the wind turbine rotor above the terrain surface

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

1.3.11
measured power curve
table and graph that represents the measured, corrected and normalized net power output of a WTGS as a function of measured wind speed, measured under a well-defined measurement procedure

1.3.12
measurement period
period during which a statistically significant database has been collected for the power performance test

1.3.13
measurement sector
a sector of wind directions from which data are selected for the measured power curve

1.3.14
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.

1.3.15
net electric power output
measure of the WTGS electric power output that is delivered to the electrical power network

1.3.16
obstacles
stationary obstacles, such as buildings and trees, neighboring the WTGS that cause wind flow distortion

1.3.17
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

1.3.18
power coefficient
ratio of the net electric power output of a WTGS to the power available in the free stream wind over the rotor swept area

1.3.19
power performance
measure of the capability of a WTGS to produce electric power and energy

1.3.20
rated power
quantity of power assigned, generally by a manufacturer, for a specified operating condition of a component, device or equipment

NOTE – (Wind turbines) Maximum continuous electrical power output which a WTGS is designed to achieve under normal operating conditions.

1.3.21
standard uncertainty
uncertainty of the result of a measurement expressed as a standard deviation

1.3.22
swept area
area of the projection, upon a plane perpendicular to the wind velocity vector, of the circle along which the rotor blade tips move during rotation

1.3.23
test site
location of the WTGS under test and its surroundings

1.3.24
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

1.4 Symbols and units

A	swept area of the WTGS rotor	[m^2]
AEP	annual energy production	[kWh]
B_{10min}	measured air pressure averaged over 10 min	[Pa]
c	sensitivity factor on a parameter (the partial differential)	
$C_{P,i}$	power coefficient in bin i	
D	rotor diameter	[m]
D_e	equivalent rotor diameter	[m]
D_n	rotor diameter of neighbouring and operating wind turbine	[m]
f_i	the relative occurrence of wind speed in a wind speed interval	
$F(V)$	the Rayleigh cumulative probability distribution function for wind speed	
l_h	height of obstacle	[m]
l_w	width of obstacle	[m]
L	distance between the WTGS and the meteorology mast	[m]
L_e	distance between the WTGS or the meteorology mast and an obstacle	[m]
L_n	distance between the WTGS or the meteorology mast and a neighbouring and operating wind turbine	[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 bin i	
N_k	number of pre-processed data sets within a 10 min period	
N_s	number of data samples of pre-processed data sets	
P_i	normalized and averaged power output in bin i	[kW]

P_n	normalized power output	[kW]
$P_{n,i,j}$	normalized power output of data set j in bin i	
P_{10min}	measured power averaged over 10 min	[kW]
R	gas constant	[J/(kg×K)]
s	uncertainty component of category A	
T_{10min}	measured absolute air temperature averaged over 10 min	[K]
u	uncertainty component of category B	
u_{AEP}	combined standard uncertainty in the estimated annual energy production	[kWh]
$u_{c,i}$	combined standard uncertainty of the power in bin i	[kW]
V	wind speed	[m/s]
V_{ave}	annual average wind speed at hub height	[m/s]
V_i	normalized and averaged wind speed in bin i	[m/s]
V_n	normalized wind speed	[m/s]
$V_{n,i,j}$	normalized wind speed of data set j in bin i	[m/s]
V_{10min}	measured wind speed averaged over 10 min	[m/s]
X_k	parameter averaged over pre-processing time period	
X_{10min}	parameter averaged over 10 min	
ρ	correlation coefficient	
ρ_0	reference air density	[kg/m^3]
ρ_{10min}	derived air density averaged over 10 min	[kg/m^3]
σ_k	standard deviation of pre-processed parameter	
$\sigma_{P,i}$	standard deviation of the normalized power data in bin i	[kW]
σ_{10min}	standard deviation of parameter averaged over 10 min	

1.5 Abbreviations

WTGS wind turbine generator system

2 Test conditions

The specific test conditions related to the power performance measurement of the WTGS shall be well defined and documented in the test report, as detailed in clause 6.

2.1 Wind turbine generator system

As detailed in clause 6, the WTGS shall be described and documented to identify uniquely the specific machine configuration that is tested.

2.2 Test site

At the test site a meteorological mast shall be set up in the neighbourhood of the WTGS to determine the speed of the wind that drives the wind turbine. The test site may have significant influence on the measured power performance of the WTGS. In particular, flow distortion effects may cause the wind speed at the meteorological mast and at the WTGS to be different, though correlated.

The test site shall be assessed for sources of wind flow distortion in order to:

– choose the position of the meteorological mast;
– define a suitable measurement sector;
– estimate appropriate flow distortion correction factors;
– evaluate the uncertainty due to wind flow distortion.

The following factors shall be considered in particular:

– topographical variations;
– other wind turbines;
– obstacles (buildings, trees, etc.).

The test site shall be documented as detailed in clause 6.

2.2.1 Distance of meteorological mast

Care shall be taken in locating the meteorological mast. It shall not be located too close to the WTGS, since the wind speed will be slowed down in front of the WTGS. Also, it shall not be located too far from the WTGS, since the correlation between wind speed and electric power output will be reduced. The meteorological mast shall be positioned at a distance from the WTGS of between 2 and 4 times the rotor diameter D of the WTGS. A distance of 2,5 times the rotor diameter D is recommended. The meteorological mast should be positioned within the selected measurement sector. In the case of a vertical axis WTGS, D should be selected as 1,5 times the maximum horizontal rotor diameter.

Figure 1 shows the separation requirements between the meteorological mast and the WTGS. It also shows the recommended separation distance of 2,5 times the rotor diameter of the WTGS between the meteorological mast and the WTGS.

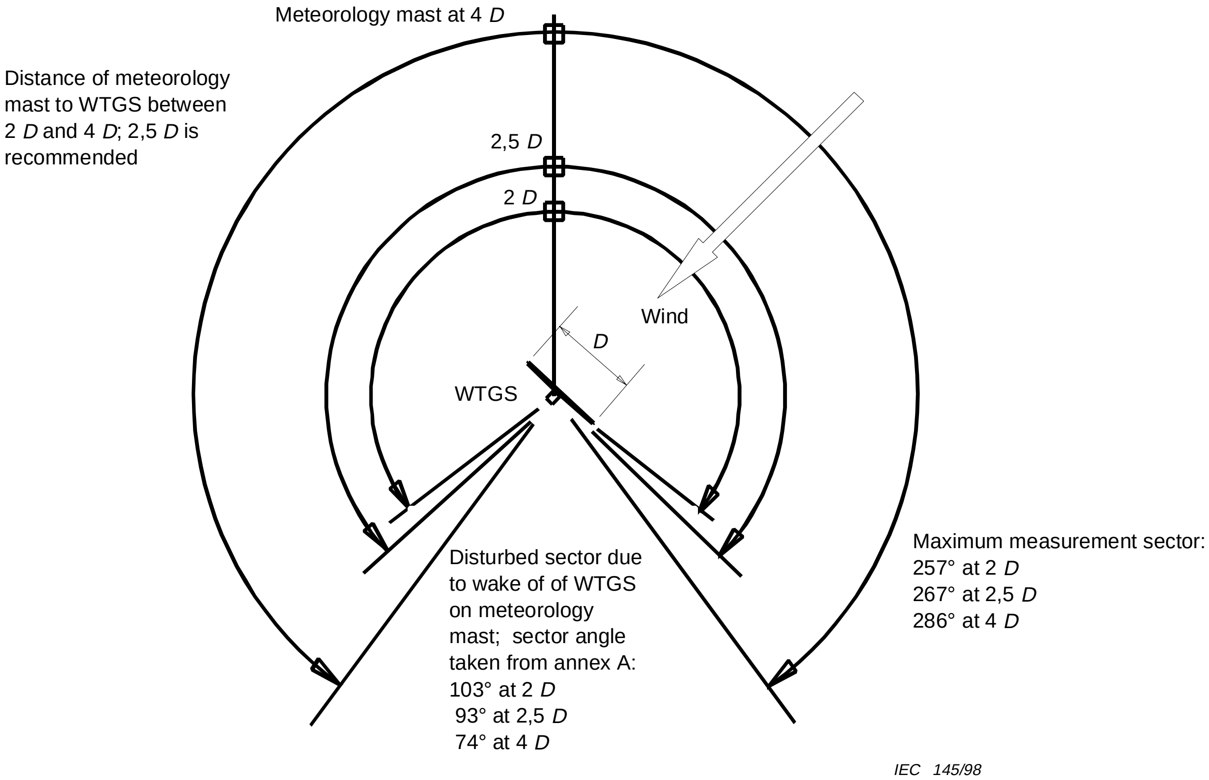


Figure 1 – Requirements as to distance of the meteorological mast and maximum allowed measurement sectors

2.2.2 Measurement sector

The measurement sector shall exclude directions having significant obstacles, significant variations in topography or other wind turbines, as seen from both the WTGS under test and the meteorological mast.

The disturbed sectors to be excluded due to the meteorological mast being in the wake of the WTGS under test are for distances of 2, 2,5 and 4 times the rotor diameter of the WTGS as shown in figure 1. For all other distances between the WTGS under test and the meteorological mast, and for all neighboring wind turbines and obstacles, the directions to be excluded due to wake effects shall be determined using the procedure in annex A.

2.2.3 Correction factors and uncertainty due to flow distortion at the test site

If the test site meets the requirements defined in annex A, then no further site analysis is required, and no flow distortion correction factors are necessary. The applied standard uncertainty due to flow distortion of the test site shall be taken to be 2 % or greater of the measured wind speed if the meteorological mast is positioned at a distance between 2 and 3 times the rotor diameter of the WTGS and 3 % or greater if the distance is 3 to 4 times the rotor diameter.

If the test site does not meet the requirements defined in annex A, or a smaller uncertainty due to flow distortion of the test site is required, then either an experimental test site calibration or a test site analysis with a three-dimensional flow model, which is validated for the relevant type of terrain, shall be undertaken.

If an experimental test site calibration is undertaken, it is recommended that the procedure in annex B be used. The measured flow distortion correction factors for each sector should be used. The standard uncertainty assigned to the site correction shall be no less than one-third of the maximum correction found within the entire measurement sector and the 60° sector centred on the predominant test wind direction.

If a theoretical assessment of the correction factors for the test site is undertaken, using a valid three-dimensional flow model, then sectors less than or equal to 30° should be used. The standard uncertainty assigned to the site correction shall be no less than half of the maximum correction found within the entire measurement sector and the 60° sector centred on the predominant test wind direction.

Although the site calibration procedure (annex B) can be used for determination of the performance characteristics of individual wind turbines within a wind power station, it is important to evaluate the consistency of the results in very complex terrain.

3 Test equipment

3.1 Electric power

The net electric power of the WTGS shall be measured using a power measurement device (e.g. power transducer) and be based on measurements of current and voltage on each phase.

The class of the current transformers shall meet the requirements of IEC 60044-1 and the class of the voltage transformers, if used, shall meet the requirements of IEC 60186. They are all recommended to be of class 0,5 or better.

The accuracy of the power measurement device, if it is a power transducer, shall meet the requirements of IEC 60688 and is recommended to be class 0,5 or better. If the power measurement device is not a power transducer then the accuracy should be equivalent to class 0,5 power transducers. The operating range of the power measurement device shall be set to measure all positive and negative instantaneous power peaks generated by the WTGS. As a guide, the full-scale range of the power measurement device should be set to –50 % to 200 % of the WTGS rated power. All data shall be periodically reviewed during the test to ensure that the range limits of the power measurement device have not been exceeded. The power measurement device shall be mounted at the network connection point to ensure that only the net active power output, delivered to the electrical power network, is measured.

3.2 Wind speed

Wind speed measurements shall be made with a cup anemometer that is properly installed at hub height on a meteorological mast, at a point that represents the free stream wind flow that drives the WTGS.

The wind speed shall be measured with a cup anemometer that has a distance constant of less than 5 m and maintains its calibration over the duration of the measurement period. Calibration of the anemometer shall have been undertaken before and after the completion of the power performance test to a traceable standard. The second calibration can be replaced by an *in situ* comparison against another calibrated reference anemometer, mounted at a distance of 1,5 m to 2 m from the hub height anemometer, during the measurement period. During calibration, the anemometer should be mounted on a configuration similar to the one to be used during the power performance test. The measurement uncertainty of the anemometer shall be stated.

The anemometer shall be mounted within ±2,5 % of hub height, preferably on the top of a vertical circular tube standing clear of the top of the meteorological mast. As an alternative, the anemometer may be mounted on a boom clamped to the side of the mast and pointing in the predominant wind direction.

Care shall be taken to minimize flow disturbance experienced in the vicinity of the anemometer. To reduce flow effects, the anemometer shall be mounted so that its vertical separation from any mounting boom is at least 7 times the boom diameter and its horizontal separation from the mast at the anemometer height is at least 7 times the maximum mast diameter; the mast being of a tube, cone, or lattice type. No other instrument shall be mounted so that the flow, incident upon the anemometer, could be disturbed.

Any corrections, which are applied to the indicated wind speed to take account of factors such as flow distortion due to the site, shall be reported clearly. The uncertainty in the correction shall also be assessed and reported, and typically shall be no less than half the difference between the corrected and uncorrected value.

3.3 Wind direction

Wind direction measurements shall be made with a wind vane that is mounted on the meteorological mast within 10 % of the hub height. Proper attention shall be paid to the positioning of the wind vane to avoid wind flow distortion between the anemometer and the vane. The absolute accuracy of the wind direction measurement should be better than 5°.

3.4 Air density

Air density shall be derived from the measurement of air temperature and air pressure using equation (3). At high temperatures it is recommended also to measure relative humidity and to correct for it.

The air temperature sensor shall be mounted at least 10 m above ground level. It should be mounted on the meteorological mast close to hub height to give a good representation of the air temperature at the WTGS rotor centre.

The air pressure sensor should be mounted on the meteorological mast close to hub height to give a good representation of the air pressure at the WTGS rotor centre. If the air pressure sensor is not mounted close to the hub height, air pressure measurements shall be corrected to the hub height according to ISO 2533.

3.5 Precipitation

To distinguish measurements from dry and wet periods, precipitation should be monitored during the measurement period and documented in the test report.

3.6 Wind turbine generator system status

At least one parameter that indicates the operational status of the WTGS shall be monitored. The status information shall be used in the process of determining WTGS availability.

3.7 Data acquisition system

A digital data acquisition system having a sampling rate per channel of at least 0,5 Hz shall be used to collect measurements and store pre-processed data.

End-to-end calibration of the installed data acquisition system shall be performed for each signal. As a guideline, the uncertainty of the data acquisition system should be negligible compared with the uncertainty of the sensors.

4 Measurement procedure

4.1 Introduction

The objective of the measurement procedure is to collect data that meet a set of clearly defined criteria to ensure that the data are of sufficient quantity and quality to determine the power performance characteristics of the WTGS accurately. The measurement procedure shall be documented, as detailed in clause 6, so that every procedural step and test condition can be reviewed and, if necessary, repeated.

Accuracy of the measurements shall be expressed in terms of measurement uncertainty, as described in annex C. During the measurement period, data should be periodically checked to ensure high quality and repeatability of the test results. Test logs shall be maintained to document all important events during the power performance test.

4.2 Wind turbine generator system operation

During the measurement period, the WTGS shall be in normal operation, as prescribed in the WTGS operations manual, and the machine configuration shall not be changed. All data collected while the WTGS is unavailable shall be discarded.

4.3 Data collection

Data shall be collected continuously at a sampling rate of 0,5 Hz or faster. Air temperature, air pressure and precipitation, and WTGS status may be sampled at a slower rate, but at least once per minute.

The data acquisition system shall store either sampled data or pre-processed data sets as described below, or both. The pre-processed data sets shall comprise the following information on the sampled data:

– mean value;

– standard deviation;

– maximum value;

– minimum value.

The total duration of each pre-processed data set shall be between 30 s and 10 min and shall be 10 min divided by an integer number. Furthermore, if the data sets have a duration of less than 10 min, then adjacent data sets shall not be separated by a time delay. Data shall be collected until the requirements defined in 4.6 are satisfied.

4.4 Data selection

Selected data sets shall be based on 10 min periods derived from contiguous measured data. The mean and standard deviation values for each 10 min period shall, when derived from pre-processed data sets, be calculated according to the following equations:

$$X_{10\text{min}} = \frac{1}{N_\text{k}} \sum_1^{N_\text{k}} X_\text{k} \qquad (1)$$

$$\sigma_{10\text{min}} = \sqrt{\frac{1}{N_\text{k} N_\text{s} - 1} \sum_1^{N_\text{k}} \left(N_\text{s} \, (X_{10\text{min}} - X_\text{k})^2 + \sigma_\text{k}^2 (N_\text{s} - 1) \right)} \qquad (2)$$

where

N_k is the number of pre-processed data sets within a 10 min period;

X_k is the parameter averaged over pre-processing time period;

$X_{10\text{min}}$ is the parameter averaged over 10 min;

N_s is the number of data samples of pre-processed data sets;

σ_k is the standard deviation of pre-processed parameter;

σ_{10min} is the standard deviation of pre-processed parameter averaged over 10 min.

Data sets shall be excluded from the database under the following circumstances:

– WTGS unavailable;
– failure of test equipment;
– wind directions outside the measurement sector.

Data sets collected under special operational conditions (e.g. high blade roughness due to dust, salt, insects, ice) or atmospheric conditions (e.g. precipitation, wind shear) that occur during the measurement period may be selected as a special database, and the selection criteria shall be stated in the measurement report.

4.5 Data correction

Selected data sets shall be corrected for flow distortion (see 2.2) and for air pressure if measured at a height other than close to hub height (see 3.4). Corrections may be applied to measurements if it can be shown that better accuracy can be obtained (for example, anemometer corrections for errors due to over-speeding at high turbulence sites).

4.6 Database

After data normalization (see 5.1) the selected data sets shall be sorted using the “method of bins” procedure (see 5.2). The selected data sets shall cover a wind speed range extending from 1 m/s below cut-in to 1,5 times the wind speed at 85 % of the rated power of the WTGS. Alternatively, the wind speed range shall extend from 1m/s below cut-in to a wind speed at which "*AEP*-measured" is greater than or equal to 95 % of "*AEP*-extrapolated" (see 5.3). The wind speed range shall be divided into 0,5 m/s contiguous bins centred on integer multiples of 0,5 m/s.

The database shall be considered complete when it has met the following criteria:

– each bin includes a minimum of 30 min of sampled data;
– the total duration of the measurement period includes a minimum of 180 h with the WTGS available within the wind speed range.

The database shall be presented in the test report as detailed in clause 6.

5 Derived results

5.1 Data normalization

The selected data sets shall be normalized to two reference air densities. One shall be the average of the measured air density data at the test site rounded to the nearest 0,05 kg/m^3. The other shall be the sea level air density, referring to ISO standard atmosphere (1,225 kg/m^3). No air density normalization to actual average air density is needed when the actual average air density is within 1,225 ± 0,05 kg/m^3. The air density is determined from measured air temperature and air pressure according to the equation:

$$\rho_{10min} = \frac{B_{10min}}{R \cdot T_{10min}} \tag{3}$$

where

ρ_{10min} is the derived air density averaged over 10 min;

T_{10min} is the measured absolute air temperature averaged over 10 min;

B_{10min} is the measured air pressure averaged over 10 min;

R is the gas constant 287,05 J/(kg × K).

For a stall-regulated WTGS with constant pitch and constant rotational speed, data normalization shall be applied to the measured power output according to the equation:

$$P_n = P_{10min} \cdot \frac{\rho_0}{\rho_{10min}} \tag{4}$$

where

P_n is the normalized power output;

P_{10min} is the measured power averaged over 10 min;

ρ_0 is the reference air density;

ρ_{10min} is the measured air density averaged over 10 min.

For a WTGS with active power control, the normalization shall be applied to the wind speed according to the equation:

$$V_n = V_{10min}\left(\frac{\rho_{10min}}{\rho_0}\right)^{1/3} \tag{5}$$

where

V_n is the normalized wind speed;

V_{10min} is the measured wind speed averaged over 10 min;

ρ_0 is the reference air density;

ρ_{10min} is the measured air density averaged over 10 min.

5.2 Determination of the measured power curve

The measured power curve is determined by applying the "method of bins" for the normalized data sets, using 0,5 m/s bins and by calculation of the mean values of the normalized wind speed and normalized power output for each wind speed bin according to the equations:

$$V_i = \frac{1}{N_i}\sum_{j=1}^{N_i} V_{n,i,j} \tag{6}$$

$$P_i = \frac{1}{N_i}\sum_{j=1}^{N_i} P_{n,i,j} \tag{7}$$

where

V_i is the normalized and averaged wind speed in bin i;

$V_{n,i,j}$ is the normalized wind speed of data set j in bin i;

P_i is the normalized and averaged power output in bin i;

$P_{n,i,j}$ is the normalized power output of data set j in bin i;

N_i is the number of 10 min data sets in bin i.

The measured power curve shall be presented as detailed in clause 6.

5.3 Annual energy production (*AEP*)

The *AEP* is estimated by applying the measured power curve to different reference wind speed frequency distributions. A Rayleigh distribution, which is identical to a Weibull distribution with a shape factor of 2, shall be used as the reference wind speed frequency distribution. *AEP* calculations shall be made for annual average wind speeds of 4, 5, 6, 7, 8, 9, 10 and 11 m/s according to the equation:

$$AEP = N_h \sum_{i=1}^{N} \left[F(V_i) - F(V_{i-1}) \right] \left(\frac{P_{i-1} + P_i}{2} \right) \tag{8}$$

where

AEP is the annual energy production;

N_h is the number of hours in one year ≈ 8760;

N is the number of bins;

V_i is the normalized and averaged wind speed V in bin i;

P_i is the normalized and averaged power output in bin i.

and

$$F(V) = 1 - \exp\left(-\frac{\pi}{4} \left(\frac{V}{V_{ave}} \right)^2 \right) \tag{9}$$

where

F(V) is the Rayleigh cumulative probability distribution function for wind speed;

V_{ave} is the annual average wind speed at hub height;

V is the wind speed.

The summation is initiated by setting V_{i-1} equal to V_i – 0,5 m/s and P_{i-1} equal to 0,0 kW.

The *AEP* shall be calculated in two ways, one designated "*AEP*-measured", the other "*AEP*-extrapolated". If the measured power curve does not include data up to cut-out wind speed, the power curve shall be extrapolated from the maximum measured wind speed up to cut-out wind speed.

AEP-measured shall be obtained from the measured power curve by assuming zero power for all wind speeds above and below the range of the measured power curve.

AEP-extrapolated shall be obtained from the measured power curve by assuming zero power for all wind speeds below the lowest wind speed in the measured power curve and constant power for wind between the highest wind speed in the measured power curve and the cut-out wind speed. The constant power used for the extrapolated *AEP* shall be the power value from the bin at the highest wind speed in the measured power curve.

AEP-measured and *AEP*-extrapolated shall be presented in the test report, as detailed in clause 6. For all *AEP* calculations, the availability of the WTGS shall be set to 100 %. For given annual average wind speeds, estimations of *AEP*-measured shall be labelled as "incomplete" when calculations show that the *AEP*-measured is less than 95 % of the *AEP*-extrapolated.

Estimations of measurement uncertainty in terms of standard uncertainty of the *AEP* according to annex C, shall be reported for the *AEP*-measured for all given annual average wind speeds.

The uncertainties in *AEP*, described above, only deal with uncertainties originating from the power performance test and do not take into account uncertainties due to other important factors. Practical *AEP* forecasting should account for additional uncertainties, including those concerning: local wind distribution, local air density, high atmospheric turbulence, severe wind shear, variations in the WTGS performance within a wind power station, availability of the WTGS and WTGS performance variations due to blade roughness effects.

5.4 Power coefficient

The power coefficient, C_P, of the WTGS may be added to the test results and presented as detailed in clause 6. C_P shall be determined from the measured power curve according to the following equation:

$$C_{P,\mathrm{i}} = \frac{P_\mathrm{i}}{\frac{1}{2}\rho_0 A V_\mathrm{i}^3} \tag{10}$$

where

$C_{P,\mathrm{i}}$ is the power coefficient in bin i;

V_i is the normalized and averaged wind speed in bin i;

P_i is the normalized and averaged power output in bin i;

A is the swept area of the WTGS rotor;

ρ_0 is the reference air density.

6 Reporting format

The test report shall contain the following information:

– description of WTGS: identification of the specific WTGS configuration under test which includes, as a minimum, the following information:
  - make, type, serial number, production year,
  - verified rotor diameter,
  - rotor speed or rotor speed range,
  - rated power and rated wind speed,
  - blade data: make, type, serial numbers, number of blades, fixed or variable pitch, and verified pitch angle(s),
  - hub height and tower type;

– description of test site (see 2.2): the description of the test site shall include photographs of all measurement sectors preferably taken from the WTGS at hub height. A test site map showing the surrounding area covering a radial distance of at least 20 times the WTGS rotor diameter and indicating the topography, location of the WTGS, meteorological mast, significant obstacles, other wind turbines, and measurement sector;

– description of grid conditions at the test site, i.e. voltage, frequency and their tolerances;

– description of test equipment (see clause 3): identification of the sensors and data acquisition system, including documentation of calibrations for the sensors, transmission lines, and data acquisition system;

– description of measurement procedure (see clause 4): documentation of the procedural steps, test conditions, sampling rate, averaging time, measurement period, and test log book that records all important events during the power performance test;

– presentation of data (see 4.3 to 4.6): the data shall be presented in both tabular and graphical formats, providing statistics of measured power output as a function of wind speed and of important meteorological parameters. Scatter plots of mean, standard deviation, maximum, and minimum power output as function of wind speed and scatter plots of mean wind speed and turbulence intensity as function of wind direction for each selected data set shall be presented. Examples of scatter plots of power output for power performance test data are shown in figure 2.

Special databases consisting of data collected under special operational or atmospheric conditions should also be presented as described above;

– presentation of measured power curve for both reference air densities (see 5.1 and 5.2): tabular and graphical representations of the measured power curve shall be provided. The reference air density shall be stated in the graph and in the table. For each bin, the table shall include normalized and averaged wind speed, normalized and averaged power output, number of data sets, and standard uncertainties of category A, category B and combined (determined according to annex C). A graphical plot shall present the same data of wind speed, power output and combined uncertainty as in the table. An example of a measured power curve is provided in table 1 and a graphical plot of the power curve is provided in figure 3.

  Special power curves consisting of data collected under special operational or atmospheric conditions should also be presented as described above;

– presentation of estimated *AEP* (see 5.3): a tabular presentation of the estimated *AEP* calculated from both the measured and the extrapolated power curve shall be provided. The table shall state the reference air density and the cut-out wind speed. For each annual average wind speed the table shall include *AEP* measured, uncertainties of *AEP* measured (determined according to annex C), and *AEP* extrapolated. The table shall be labelled "incomplete" at annual average wind speeds where *AEP* measured is less than 95 % of *AEP*-extrapolated;

– presentation of power coefficient (see 5.4): tabular and graphical presentations of the power coefficient as a function of wind speed should be provided;

– uncertainty assumptions on all uncertainty components shall be provided;

– deviations: any deviations from the requirements of this standard shall be clearly documented in the test report and supported with the technical rationale for each deviation.

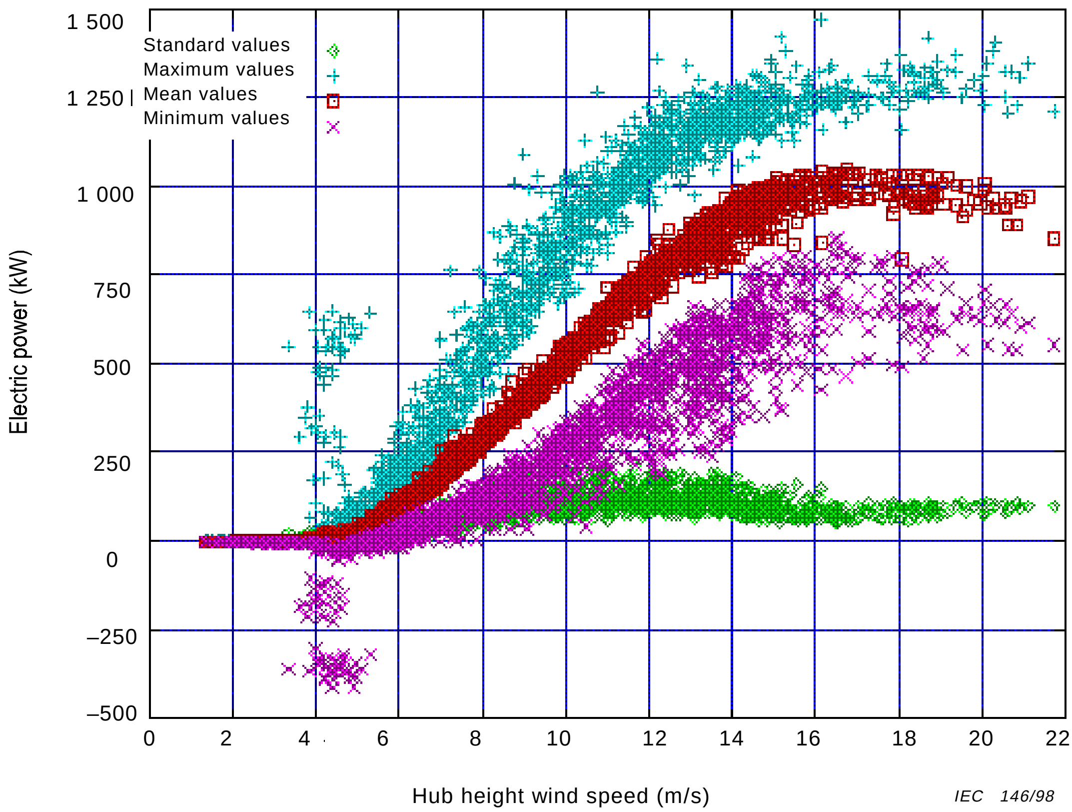


Figure 2 – Presentation of example data: power performance test scatter plots

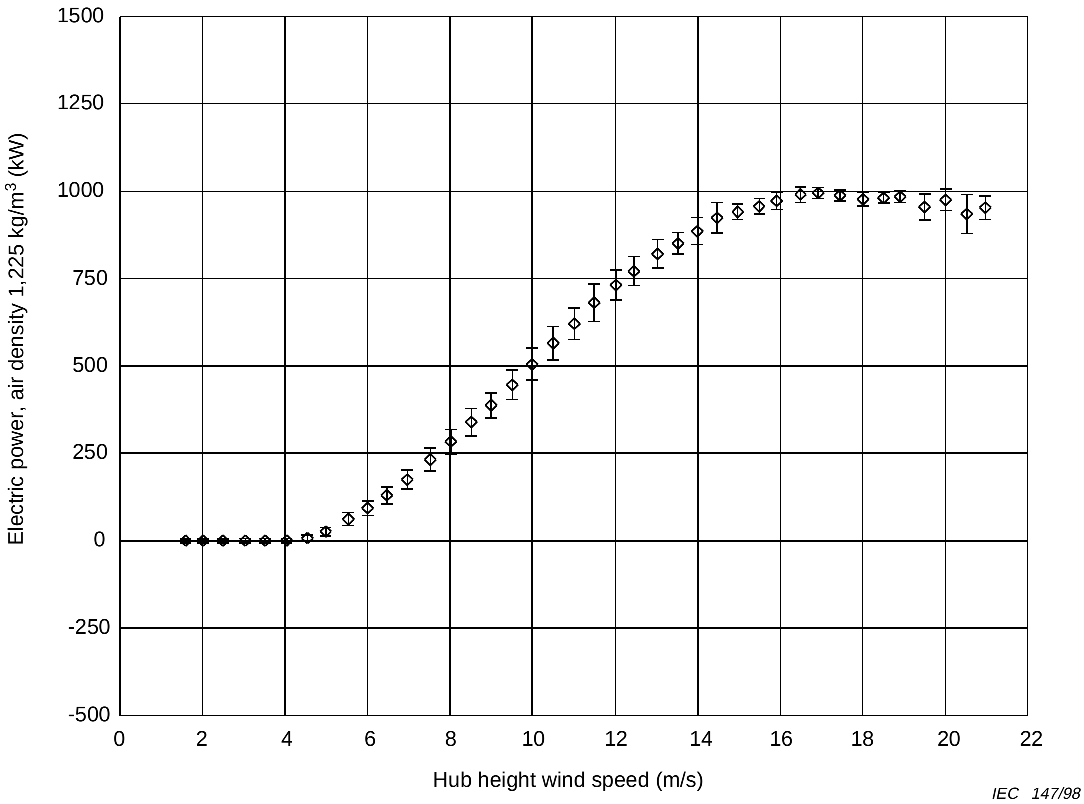


Figure 3 – Presentation of example measured power curve

Table 1 – Example of presentation of a measured power curve

Measured power curve Reference air density 1,225 kg/m^3				Category A uncertainty	Category B uncertainty	Combined uncertainty
Bin No. i	**Hub height wind speed V_i** m/s	**Power output P_i** kW	**No. of data sets N_i 10 min average**	**Standard uncertainty s_i** kW	**Standard uncertainty u_i** kW	**Standard uncertainty $u_{c,i}$** kW
1	1,59	–0,85	8	0,00	6,31	6,31
2	2,02	–0,74	15	0,08	6,30	6,30
3	2,51	–0,81	18	0,05	6,30	6,30
4	3,04	–0,50	22	0,09	6,30	6,30
5	3,53	–0,67	27	0,10	6,30	6,30
6	4,04	0,16	41	0,67	6,31	6,35
7	4,55	7,32	55	1,02	7,21	7,28
8	4,99	25,90	61	1,22	12,45	12,51
9	5,54	61,43	54	1,98	18,40	18,50
10	6,00	93,16	95	1,51	20,13	20,19
11	6,47	129,78	90	1,87	23,71	23,78
12	6,97	174,46	81	2,55	27,32	27,44
13	7,53	231,77	68	2,91	33,10	33,23
14	8,02	283,63	61	2,79	34,56	34,67
15	8,52	339,55	73	3,56	39,19	39,35
16	9,00	387,22	69	3,36	35,38	35,54
17	9,51	445,98	69	2,91	42,88	42,98
18	9,99	504,41	81	2,58	46,23	46,30
19	10,50	565,17	79	2,86	47,72	47,80
20	11,01	620,67	74	3,73	44,69	44,85
21	11,50	680,87	78	3,07	53,04	53,13
22	12,02	731,22	85	3,42	43,10	43,24
23	12,46	770,77	60	4,00	41,44	41,64
24	13,03	820,11	102	2,63	41,46	41,55
25	13,53	850,86	88	3,57	31,81	32,01
26	13,99	884,94	79	4,68	37,79	38,08
27	14,47	923,82	85	3,36	42,99	43,12
28	14,98	940,46	61	4,59	21,13	21,62
29	15,49	956,59	28	7,35	21,01	22,25
30	15,92	972,27	27	7,19	23,81	24,87
31	16,50	990,54	33	3,46	21,99	22,26
32	16,93	994,74	14	7,80	14,15	16,16
33	17,45	987,43	12	3,00	15,38	15,67
34	18,01	976,59	23	10,26	17,36	20,16
35	18,51	980,11	23	4,71	13,58	14,37
36	18,91	984,33	13	6,84	14,52	16,05
37	19,50	954,56	5	12,15	35,38	37,40
38	20,01	975,12	7	9,84	29,91	31,49
39	20,53	934,42	8	9,46	55,36	56,16
40	20,97	952,60	5	11,97	31,26	33,47

Table 2 – Example of presentation of estimated annual energy production

Estimated annual energy production Reference air density: 1,225 kg/m^3 Cut-out wind speed: 25 m/s (extrapolation by constant power from last bin)			
Hub height annual average wind speed (Rayleigh) m/s	***AEP*-measured (measured power curve)** MWh	**Uncertainty of measured power curve in terms of standard deviation of *AEP*** MWh, %	***AEP*-extrapolated (extrapolated power curve)** MWh
4	412	111 27 %	412
5	911	154 17 %	911
6	1 536	191 12 %	1 536
7	2 207	219 10 %	2 214
8	2 847	236 8 %	2 880
9	3 395	245 7 %	3 487
10	3 812	248 6 %	4 001
11	4 092 incomplete	245 6 %	4 403

Annex A
(normative)

Assessment of test site

The test site shall be assessed to determine whether it can meet the requirements in this annex.

A.1 Requirements regarding topographic variations

The terrain at the test site shall, up to a certain distance from the WTGS, only show minor variations from a plane which passes both through the base of the tower of the WTGS and the terrain within the sectors specified in table A.1. The slope of the plane and variations of the terrain from the plane shall comply with the requirements provided in table A.1 and shown in figure A.1, where *L* is the distance between the WTGS and the meteorological mast and *D* is the rotor diameter of the WTGS. In the case of a vertical axis WTGS, *D* should be selected as the maximum horizontal rotor diameter.

Table A.1 – Test site requirements: topographical variations

Distance	Sector	Maximum slope %	Maximum terrain variation from plane
<2 *L*	360°	<3*	<0,08 *D*
≥2 *L* and < 4 *L*	measurement sector	<5*	<0,15 *D*
≥2 *L* and <4 *L*	outside measurement sector	<10**	Not applicable
≥4 *L* and <8 *L*	measurement sector	<10*	<0,25 *D*

* The maximum slope of the plane, which provides the best fit to the sectoral terrain and passes through the tower base.

** The line of steepest slope that connects the tower base to individual terrain points within the sector.

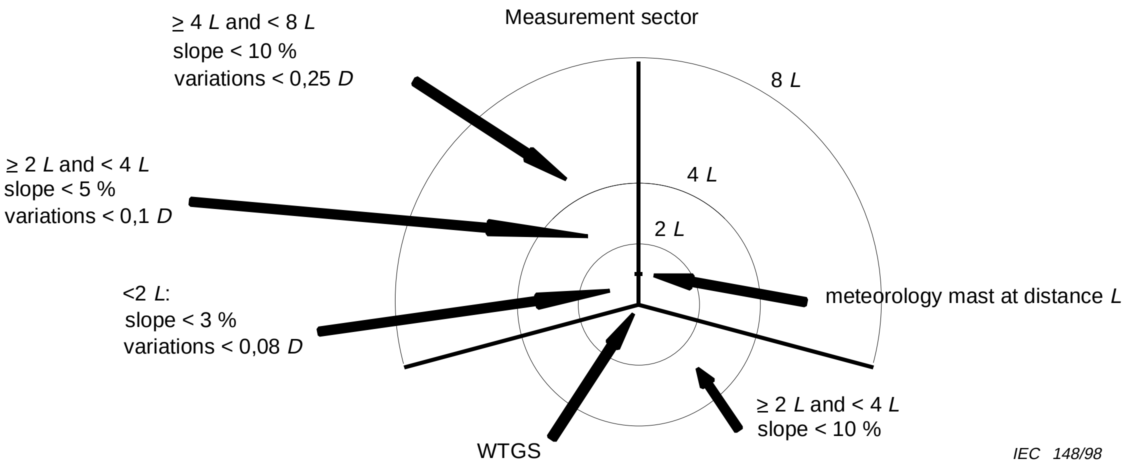


Figure A.1 – Requirements to topographical variations, top view

A.2 Requirements regarding neighbouring and operating wind turbines

The WTGS under test and the meteorological mast shall not be influenced by neighbouring and operating wind turbines. The minimum distance from the WTGS under test and the meteorological mast to neighbouring and operating wind turbines shall be two rotor diameters D_n of the neighbouring wind turbine. The sectors to exclude due to wakes from neighbouring and operating wind turbines shall be taken from figure A.2. The dimensions to be taken into account are the actual distance L_n and the rotor diameter D_n of the neighbouring and operating wind turbine. The sectors to exclude shall be derived for both the WTGS under test and the meteorological mast, and they shall be centred on the direction from the neighbouring and operating wind turbine to the meteorological mast or the WTGS. An example is shown in figure A.3. Stopped wind turbines shall be regarded as obstacles.

A.3 Requirements regarding obstacles

No significant obstacles (e.g. buildings, trees, parked wind turbines) shall exist in the measurement sector within a reasonable distance from the WTGS and meteorological mast. Only small buildings, connected to the WTGS or the measurement equipment, are acceptable. Obstacles smaller than the allowable terrain variations, as defined above, can be neglected. The sectors to exclude due to wakes of significant obstacles shall be taken from figure A.2. The dimensions to be taken into account are the actual distance L_e and an equivalent rotor diameter D_e of the obstacle. The equivalent rotor diameter of the obstacle shall be defined as:

$$D_e = \frac{2\, l_h\, l_w}{l_h + l_w} \qquad \text{(A.1)}$$

where

D_e is the equivalent rotor diameter;

l_h is the height of obstacle;

l_w is the width of obstacle.

The sectors to exclude shall be derived for both the WTGS under test and the meteorological mast. They shall be centred on the direction from the obstacle to the meteorological mast or the direction from the obstacle to the WTGS. An example is shown in figure A.3. For stopped wind turbines, l_h should be set to the total height, and l_w to the largest of either the tower diameter close to the nacelle or to the largest blade chord.

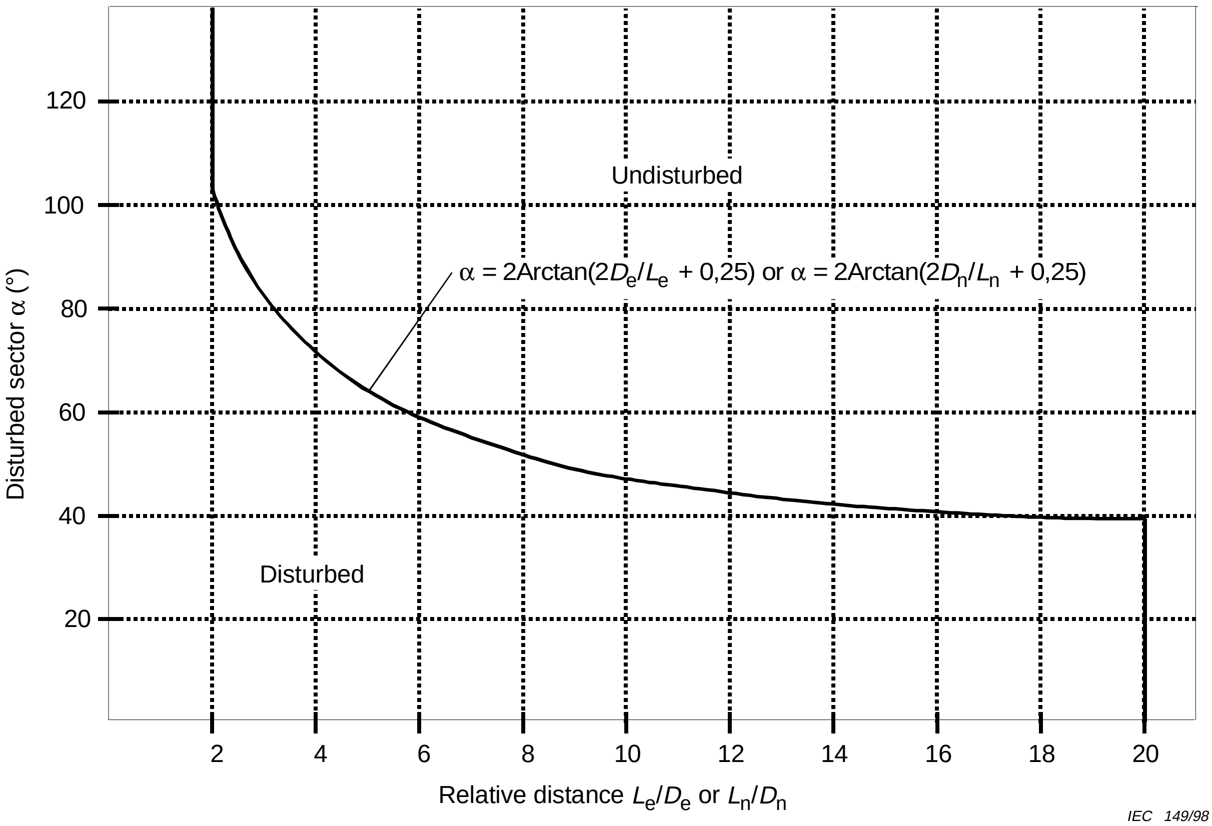
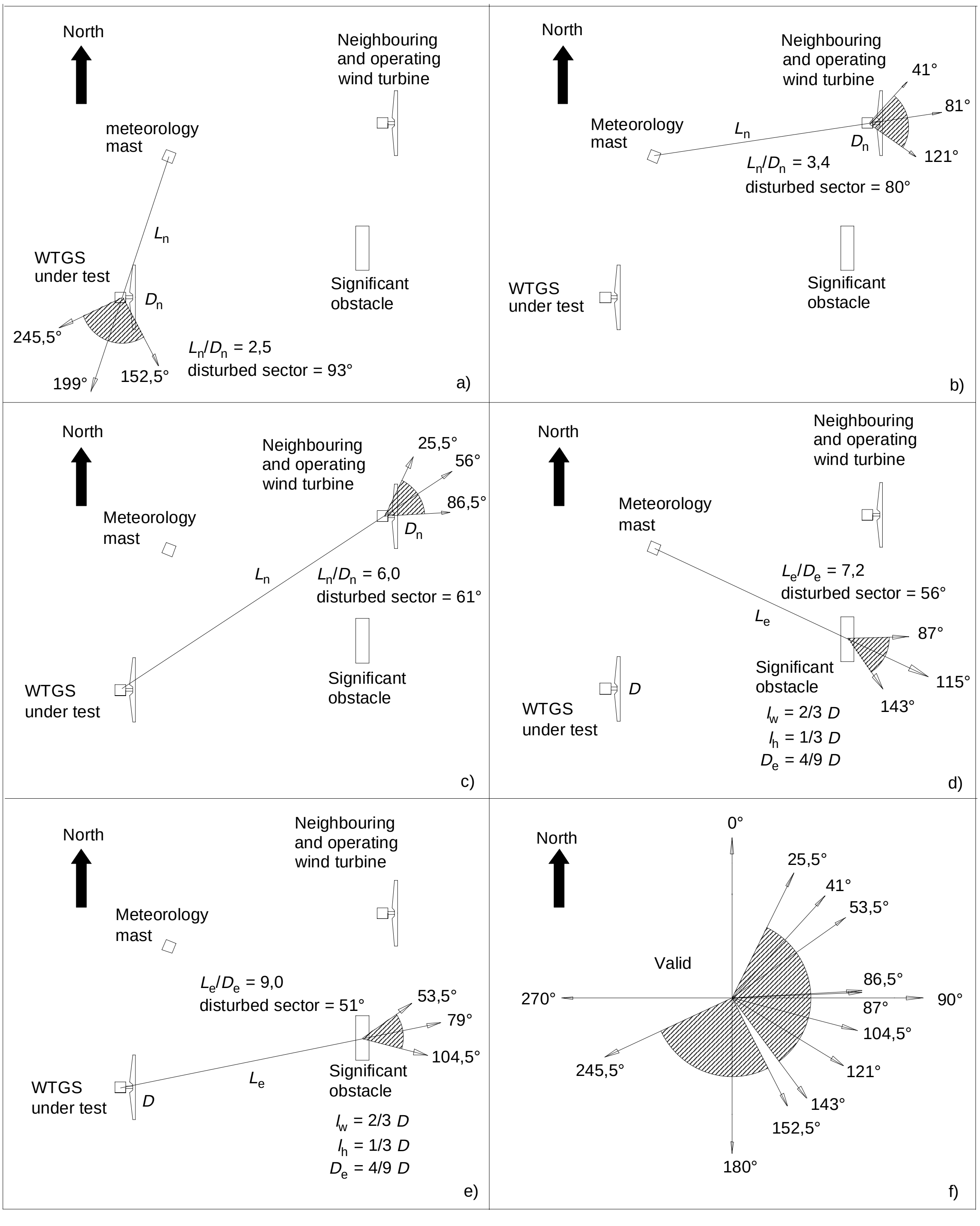


Figure A.2 – Sectors to exclude due to wakes of neighbouring and operating wind turbines and significant obstacles



The figures show the sectors to exclude when:

a) the meteorological mast is in the wake of the WTGS under test;
b) the meteorological mast is in the wake of the neighbouring and operating wind turbine;
c) the WTGS is in the wake of the neighbouring and operating wind turbine;
d) the meteorological mast is in the wake of the significant obstacle;
e) the WTGS is in the wake of the significant obstacle;
f) all of the above effects a) to e) are combined.

Figure A.3 – An example of sectors to exclude due to wakes of the WTGS under test, a neighbouring and operating wind turbine and a significant obstacle

Annex B
(informative)

Calibration of test site

The aim of an experimental calibration of the test site is to determine the flow distortion correction factors due to the test site topography. Calibration of a test site should be performed by collecting wind speed and wind direction data at hub height on a temporary meteorological mast erected at the foundation where the WTGS to be tested will be erected and at the meteorological mast that will be used for the power performance test.

The measurements of wind speeds and wind directions should follow the requirements of clause 3. Data collection should follow the procedures described in 4.3 and data selection should follow 4.4. Data should be sorted in wind direction sectors of a maximum of 30° width. For each wind direction sector, a minimum of 24 h of data at wind speeds ranging from 5 m/s to 10 m/s should be acquired.

For the meteorological masts, flow distortion correction factors should be established for each wind direction sector by regressing the measured wind data from the wind turbine location on the measured wind data from the reference mast.

The uncertainties connected to the measurement of the flow distortion correction factors should be derived from the measurements. Procedures for the uncertainty analysis as described in annex C should be applied. The estimated uncertainty should be used when applying the flow distortion correction factors, but the uncertainty should not be stated less than required in 2.2.3.

Annex C
(normative)

Evaluation of uncertainty in measurement

This annex addresses the requirements for the determination of uncertainty in measurement. The theoretical basis for determining the uncertainty using the method of bins, with a worked example of estimating uncertainties, can be found in annex D.

The measured power curve shall be supplemented with an estimate of the uncertainty of the measurement. The estimate shall be based on the ISO information publication "Guide to the expression of uncertainty in measurement".

Following the ISO guide, there are two types of uncertainties: category A, the magnitude of which can be deduced from measurements, and category B, which are estimated by other means. In both categories, uncertainties are expressed as standard deviations and are denoted standard uncertainties.

<u>The measurands</u>

The measurands are the power curve, determined by the measured and normalized bin values of electric power and wind speed (see 5.1 and 5.2), and the estimated annual energy production (see 5.3). Uncertainties in the measurements are converted to uncertainty in the measurand by means of sensitivity factors.

<u>Uncertainty components</u>

Table C.1 provides a minimum list of uncertainty parameters that shall be included in the uncertainty analysis.

Table C.1 – List of uncertainty components

Measured parameter	Uncertainty component	Uncertainty category
Electric power	Current transformers	B
	Voltage transformers	B
	Power transducer or power measurement device	B
	Data acquisition system (see below)	B
	Variability of electric power	A
Wind speed	Anemometer calibration	B
	Operational characteristics	B
	Mounting effects	B
	Data acquisition system (see below)	B
	Flow distortion due to terrain	B
Air temperature	Temperature sensor	B
	Radiation shielding	B
	Mounting effects	B
	Data acquisition system (see below)	B
Air pressure	Pressure sensor	B
	Mounting effects	B
	Data acquisition system (see below)	B
Data acquisition system	Signal transmission	B
	System accuracy	B
	Signal conditioning	B

Annex D
(informative)

Theoretical basis for determining the uncertainty of measurement using the method of bins

In its most general form the combined standard uncertainty of the power in bin i, $u_{c,i}$ can be expressed by:

$$u_{c,i}^2 = \sum_{k=1}^{M} \sum_{l=1}^{M} c_{k,i} \; u_{k,i} \; c_{l,i} \; u_{l,i} \; \rho_{k,l,i,j} \tag{D.1}$$

where

$c_{k,i}$ is the sensitivity factor of component k in bin i;

$u_{k,i}$ is the standard uncertainty of component k in bin i;

M is the number of uncertainty components in each bin;

$\rho_{k,l,i,j}$ is the correlation coefficient between uncertainty component k in bin i and uncertainty component l in bin j (in the expression the components k and l are both in bin i).

The uncertainty component is the individual input quantity to the uncertainty of each measured parameter.

The combined standard uncertainty in the estimated annual energy production, u_{AEP}, can in its most general form be expressed by:

$$u_{AEP}^2 = N_h^2 \; \sum_{i=1}^{N} \; \sum_{j=1}^{N} \sum_{k=1}^{M} \; \sum_{l=1}^{M} f_i \; c_{k,i} \, u_{k,i} \, f_j \; c_{l,j} \; u_{l,j} \; \rho_{k,l,i,j} \tag{D.2}$$

where

f_i is the relative occurrence of wind speed between V_{i-1} and V_i: $F(V_i) - F(V_{i-1})$ within bin i;

$F(V)$ is the Rayleigh cumulative probability distribution function for wind speed;

N is the number of bins;

N_h is the number of hours in one year ≈ 8760.

It is seldom possible to deduce explicitly all the values of the correlation coefficients $\rho_{k,l,i,j}$ and normally significant simplifications are necessary.

To allow the above expressions of combined uncertainties to be simplified to a practical level, the following assumptions may be made:

– uncertainty components are either fully correlated ($\rho = 1$, implying linear summation to obtain the combined standard uncertainty) or independent ($\rho = 0$, implying quadratic summation, i.e. the combined standard uncertainty is the square root of summed squares of the uncertainty components);

– all uncertainty components (they are of either category A or B) are independent of each other (either they are from the same bin or they are from different bins), except category B uncertainty components, which are fully correlated with category B components of the same origin (e.g. uncertainty in power transducer) in different bins.

Using these assumptions, the combined uncertainty of the power within a bin, $u_{c,i}$, can be expressed by:

$$u_{c,i}^2 = \sum_{k=1}^{M_A} c_{k,i}^2 \; s_{k,i}^2 + \sum_{k=1}^{M_B} c_{k,i}^2 u_{k,i}^2 = s_i^2 + u_i^2 \qquad \text{(D.3)}$$

where

M_A is the number of category A uncertainty components;

M_B is the number of category B uncertainty components;

$s_{k,i}$ is the category A standard uncertainty of component k in bin i;

s_i are the combined category A uncertainties in bin i;

u_i are the combined category B uncertainties in bin i.

It should be noted that $u_{c,i}{}^2$ is not independent of bin size due to the dependency of $s_{P,i}$ on the number of data sets in the bin (see equation D.10).

The assumptions imply that the combined standard uncertainty in energy production, u_{AEP}, is:

$$u_{AEP}^2 = N_h^2 \; \sum_{i=1}^{N} \; f_i^2 \; \sum_{k=1}^{M_A} \; c_{k,i}^2 \; s_{k,i}^2 \; + \; N_h^2 \; \sum_{k=1}^{M_B} (\sum_{i=1}^{N} f_i \; c_{k,i} \; u_{k,i})^2 \qquad \text{(D.4)}$$

The significance of the second term in this equation is that each individual category B uncertainty component progresses through to the corresponding *AEP* uncertainty, applying the assumption of full correlation across bins for the individual components. Finally, the cross-bin combined uncertainty components are added quadratically into a resulting *AEP* uncertainty.

In practice, it may not be convenient to sum category B uncertainty components across the bins before they are individually combined. An approximation, allowing the category B uncertainty components to be combined within bins before they are combined across bins (i.e. s_i and u_i can be used), leads to the more convenient expression:

$$\begin{aligned} u_{AEP}^2 &= N_h^2 \sum_{i=1}^{N} f_i^2 \sum_{k=1}^{M_A} c_{k,i}^2 \; s_{k,i}^2 + N_h^2 (\sum_{i=1}^{N} f_i \sqrt{\sum_{k=1}^{M_B} c_{k,i}^2 \; u_{k,i}^2})^2 = \\ &N_h^2 \sum_{i=1}^{N} f_i^2 \; s_i^2 + N_h^2 (\sum_{i=1}^{N} f_i \, u_i)^2 \end{aligned} \qquad \text{(D.5)}$$

The u_{AEP}, obtained by this expression is always equal to or larger than that obtained using equation D.4.

<u>Expanded uncertainty</u>

The combined standard uncertainties of the power curve and the *AEP* may additionally be expressed by expanded uncertainties. Referring to the ISO guide and assuming normal distributions, intervals having levels of confidence shown in table D.1 can be found by multiplying the standard uncertainties by a coverage factor also shown in the table.

Table D.1 – Expanded uncertainties

Level of confidence %	Coverage factor
68,27	1
90	1,645
95	1,960
95,45	2
99	2,576
99,73	3

Example

The following example goes through an estimate of the category A and B uncertainties for each bin of a measured power curve. The uncertainty of the power curve is derived, and finally the uncertainty of *AEP* is estimated.

The example follows the ISO guide and the assumptions made above. Using the combination of the category B uncertainty components according to equation D.5, all uncertainty components within each bin can be combined first to express the combined category B uncertainty of each measured parameter, as for example for the wind speed:

$$u_{\mathrm{V,i}}^2 = u_{\mathrm{V1,i}}^2 + u_{\mathrm{V2,i}}^2 + \dots \tag{D.6}$$

where uncertainty components refer to the uncertainty components in table D.2, using symbols and indices as in the table. Secondly, the standard uncertainties of the measurands can be expressed by the uncertainties of the measurement parameters in bin i:

$$u_{\mathrm{c,i}}^2 = s_{\mathrm{P,i}}^2 + u_{\mathrm{P,i}}^2 + c_{\mathrm{V,i}}^2 u_{\mathrm{V,i}}^2 + c_{\mathrm{T,i}}^2 u_{\mathrm{T,i}}^2 + c_{\mathrm{B,i}}^2 u_{\mathrm{B,i}}^2 \tag{D.7}$$

$$u_{\mathrm{AEP}}^2 = N_{\mathrm{h}}^2 \left(\sum_{\mathrm{i}=1}^{N} f_{\mathrm{i}}^2 s_{\mathrm{P,i}}^2 + s_{\mathrm{w}}^2 + \left(\sum_{\mathrm{i}=1}^{N} f_{\mathrm{i}} \sqrt{u_{\mathrm{P,i}}^2 + c_{\mathrm{V,i}}^2 u_{\mathrm{V,i}}^2 + c_{\mathrm{T,i}}^2 u_{\mathrm{T,i}}^2 + c_{\mathrm{B,i}}^2 u_{\mathrm{B,i}}^2 + c_{\mathrm{m,i}}^2 u_{\mathrm{m,i}}^2} \right)^2 \right) \tag{D.8}$$

where uncertainties due to the data acquisition system are part of the uncertainty of each measurement parameter and flow distortion due to terrain is included in the uncertainty of wind speed. The uncertainty related to climatic variations, s_{w}, is evaluated separately.

The example only considers the uncertainty components, which shall be included in the uncertainty analysis according to table C.1. The measured power curve, shown in figures 2 and 3 and table 1, is used in the example. The power curve (for lack of pre-processed data sets) is extrapolated with a constant power, which is the power in the last bin, to the stop wind speed of 25 m/s. The results of the uncertainty analysis in the example are also shown in figure 3 and table 1. All sensitivity factors are listed in table D.3, and category B uncertainties are listed in table D.4.

<u>Category A uncertainties</u>

The only category A uncertainty that needs to be considered is the uncertainty of the measured and normalized electric power data in each bin.

Category A uncertainty in electric power

The standard deviation of the distribution of normalized power data in each bin is calculated by the equation:

$$\sigma_{P,\mathrm{i}} = \sqrt{\frac{1}{N_\mathrm{i} - 1} \sum_{\mathrm{j}=1}^{N_\mathrm{i}} \left(P_\mathrm{i} - P_{\mathrm{n,i,j}}\right)^2} \qquad \text{(D.9)}$$

where

$\sigma_{P,\mathrm{i}}$ is the standard deviation of the normalized power data in bin i;

N_i is the number of 10 min data sets in bin i;

P_i is the normalized and averaged power output in bin i;

$P_{\mathrm{n,i,j}}$ is the normalized power output of data set j in bin i.

Table D.2 – List of category B and A uncertainties

Category B: Instruments	Note	Standard	Uncertainty	Sensitivity
Power output			$u_{P,\mathrm{i}}$	$c_{P,\mathrm{i}} = 1$
Current transformers *	a	IEC 60044-1	$u_{P1,\mathrm{i}}$	
Voltage transformers *	a	IEC 60186	$u_{P2,\mathrm{i}}$	
Power transducer or *	a	IEC 60688	$u_{P3,\mathrm{i}}$	
Power measurement device *	c		$u_{P4,\mathrm{i}}$	
Wind speed			$u_{V,\mathrm{i}}$	$c_{V,\mathrm{i}} \approx \dfrac{P_\mathrm{i} - P_{\mathrm{i}-1}}{V_\mathrm{i} - V_{\mathrm{i}-1}}$
Anemometer *	b		$u_{V1,\mathrm{i}}$	
Operational characteristics *	cd		$u_{V2,\mathrm{i}}$	
Mounting effects *	c		$u_{V3,\mathrm{i}}$	
Air density				$c_{T,\mathrm{i}} \approx \dfrac{\mathrm{P_i}}{288{,}15\ \mathrm{K}}$
<u>Temperature</u>			$u_{T,\mathrm{i}}$	
Temperature sensor *	a		$u_{T1,\mathrm{i}}$	$c_{B,\mathrm{i}} \approx \dfrac{P_\mathrm{i}}{1013\ \mathrm{hPa}}$
Radiation shielding *	cd		$u_{T2,\mathrm{i}}$	
Mounting effects *			$u_{T3,\mathrm{i}}$	
<u>Air pressure</u>		ISO 2533	$u_{B,\mathrm{i}}$	
Pressure sensor *	a		$u_{B1,\mathrm{i}}$	
Mounting effects *	c		$u_{B2,\mathrm{i}}$	
Data acquisition system			$u_{\mathrm{d,i}}$	Sensitivity factor is derived from actual uncertainty parameter
Signal transmission *	b		$u_{\mathrm{d1,i}}$	
System accuracy *	cd		$u_{\mathrm{d2,i}}$	
Signal conditioning *			$u_{\mathrm{d3,i}}$	
Category B: Terrain				
Flow distortion due to terrain *	bc		$u_{V4,\mathrm{i}}$	$c_{V,\mathrm{i}}$ (see above)
Category B: Method				
Method			$u_{\mathrm{m,i}}$	
Air density correction	cd		$u_{\mathrm{m1,i}}$	$c_{T,\mathrm{i}}$ and $c_{B,\mathrm{i}}$
Method of bins	c		$u_{\mathrm{m2,i}}$	(see above)
				–--
Category A: Statistical				
Electric power *	e		$s_{P,\mathrm{i}}$	$c_{P,\mathrm{i}} = 1$
Climatic variations	e		s_W	–--

* parameter required for the uncertainty analysis

NOTE – Identification of uncertainties:
a = reference to standard
b = calibration
c = other "objective" method
d = "guestimate"
e = statistics

The standard uncertainty of the normalized and averaged power in the bin is estimated by the equation:

$$s_i = s_{P,i} = \frac{\sigma_{P,i}}{\sqrt{N_i}} \tag{D.10}$$

where

$s_{P,i}$ is the category A standard uncertainty of power in bin i;

$\sigma_{P,i}$ is the standard deviation of the normalized power data in bin i;

N_i is the number of 10 min data sets in bin i.

Category A uncertainties in climatic variations

The power performance test may have been carried out under special atmospheric conditions that affect the test result systematically, such as very stable (large vertical shear and low turbulence) or unstable (little shear and high turbulence) atmospheric stratification or frequent and/or large changes in wind direction. The order of magnitude of this uncertainty can be tested by: a) subdividing the data record into segments, each long enough to have small (statistical) uncertainty on power, b) estimate annual energy production for each of the derived power curves, and c) calculate the standard deviation of the annual energy production estimates.

Category B uncertainties

The category B uncertainties are assumed to be related to the instruments, the data acquisition system, and the terrain surrounding the power performance test site. If the uncertainties are expressed as uncertainty limits, or have implicit, non-unity coverage factors, the standard uncertainty must be estimated or they must be properly converted into standard uncertainties.

NOTE – Consider an uncertainty expressed as an uncertainty limit $\pm U$. If a rectangular probability distribution is assumed, the standard uncertainty is:

$$\sigma = \frac{U}{\sqrt{3}} \tag{D.11}$$

If a triangular probability distribution is assumed, the standard uncertainty is:

$$\sigma = \frac{U}{\sqrt{6}} \tag{D.12}$$

Category B uncertainties in the data acquisition system

There may be uncertainties from transmission, signal conditioning, analogue to digital conversion, and data processing in the data acquisition system. The uncertainties may be different for each measurement channel. The standard uncertainty of the data acquisition system for the full range of a certain measurement channel, $u_{d,i}$, can be expressed as:

$$u_{d,i} = \sqrt{u_{d1,i}^2 + u_{d2,i}^2 + u_{d3,i}^2} \tag{D.13}$$

where

$u_{d1,i}$ is the uncertainty in signal transmission and signal conditioning in bin i;

$u_{d2,i}$ is the uncertainty in digitization in bin i, for example from quantization resolution;

$u_{d3,i}$ is the uncertainty in other parts of the integrated data acquisition system (software, storage system) in bin i.

We assume in this example the data acquisition system to have a standard uncertainty $u_{d,i}$ of 0,1 % of full range of each measurement channel.

<u>Category B uncertainties in electric power</u>

The uncertainty of the power sensor has uncertainty contributions from current and voltage transformers and from the power transducer. Uncertainties of these subcomponents are normally stated by their classification.

The standard uncertainty of the electric power for each bin, $u_{P,\,i}$, is calculated by combining the standard uncertainties from the power transducer, the current and voltage transformers and the data acquisition system:

$$u_{P,i} = \sqrt{u_{P1,i}^2 + u_{P2,i}^2 + u_{P3,i}^2 + u_{dP,i}^2} \qquad \text{(D.14)}$$

where

$u_{P1,i}$ is the uncertainty in current transformers in bin i;

$u_{P2,i}$ is the uncertainty in voltage transformers in bin i;

$u_{P3,i}$ is the uncertainty in the power transducer in bin i;

$u_{dP,i}$ is the uncertainty in the data acquisition system for the power channel in bin i.

In the example, the current and voltage transformers and the power transducer are all assumed to be of class 0,5.

The current transformers of class 0,5 (nominal loads of the current transformers are here designed to match the nominal power, 1 000 kW, and not 200 % of nominal power). They have uncertainty limits, referring to IEC 60044-1, of ±0,5 % of the current at 100 % load. At 20 % and 5 % loads, though, the uncertainty limits are increased to ±0,75 % and ±1,5 % of the current, respectively. For power performance measurements on WTGS, the most important energy production is produced at a reduced power. Thus, we anticipate the uncertainty limits of ±0,75 % of the current at 20 % load to be a good average. The uncertainty distribution is assumed to be rectangular. The uncertainties of the three current transformers are assumed to be caused by external influence factors such as air temperature, grid frequencyn etc. They are therefore assumed fully correlated (an exception from the general assumption) and are summed linearly. As each current transformer contributes by one-third to the power measurement, it follows that the uncertainty of all current transformers is proportional to the power as follows:

$$u_{P1,i} = \frac{0{,}75\ \% \cdot P_i\,[\text{kW}]}{\sqrt{3}}\ \frac{1}{3}\ 3\ =\ 0{,}43\ \% \cdot P_i\ [\text{kW}] \qquad \text{(D.15)}$$

The voltage transformers of class 0,5, have uncertainty limits, referring to IEC 60186, of ±0,5 % of the voltage at all loads. The uncertainty distribution is assumed to be rectangular. The grid voltage is normally rather constant and independent of the WTGS power. The uncertainties of the three voltage transformers are as for the current transformers assumed to be caused by external influence factors such as air temperature, grid frequency, etc. They are therefore assumed fully correlated (an exception from the general assumption) and are summed linearly. As each voltage transformer contributes by one-third to the power measurement, it follows that the uncertainty of all voltage transformers is proportional to the power as follows:

$$u_{P2,i} = \frac{0{,}5\ \% \cdot P_i\,[\text{kW}]}{\sqrt{3}}\ \frac{1}{3}\ 3\ =\ 0{,}29\ \% \cdot P_i\,[\text{kW}] \qquad \text{(D.16)}$$

If current and voltage transformers are not operated within their secondary loop operational load limits, additional uncertainties shall be added.

The power transducer of class 0,5, referring to IEC 60688, with a nominal power of 2 000 kW (200 % of the nominal power, 1 000 kW, of the WTGS) has an uncertainty limit of 10 kW. The uncertainty distribution is assumed to be rectangular. The uncertainty of the power transducer is thus:

$$u_{P3,\mathrm{i}} = \frac{10\ \mathrm{kW}}{\sqrt{3}} = 5{,}8\ \mathrm{kW} \tag{D.17}$$

Considering the electric power range of the measurement channel to be 2 500 kW and an uncertainty of the data acquisition system of 0,1% of this range, the standard uncertainty from the electric power sensor for each bin is:

$$\begin{aligned} u_{\mathrm{P,i}} &= \sqrt{(0{,}43\ \% \cdot P_\mathrm{i}\,[\mathrm{kW}]\,)^2 + (0{,}29\ \% \cdot P_\mathrm{i}\,[\mathrm{kW}]\,)^2 + (5{,}8\ \mathrm{kW}\,)^2 + (0{,}1\ \% \cdot 2\ 500\ \mathrm{kW}\,)^2} \\ &= \sqrt{(0{,}52\ \% \cdot P_\mathrm{i}\,[\mathrm{kW}]\,)^2 + (6{,}3\ \mathrm{kW}\,)^2} \end{aligned} \tag{D.18}$$

Category B uncertainties in wind speed

The uncertainty of the wind speed measurement is a combination of several uncertainty components. Usually, the most important ones are flow distortion due to the terrain, the mounting effects on the anemometer, and the uncertainty of the anemometer calibration. If the terrain complies with the terrain requirements of annex A the flow distortion due to the terrain is determined as 2 % or 3 %, dependent on the distance of the meteorological mast from the WTGS. If an experimental test site calibration is undertaken according to annex B, the standard uncertainty derived from the calibration shall be used, but it may not be less than one-third of the maximum flow distortion. If a test site analysis with a three-dimensional flow model is undertaken an uncertainty not less than one-half of the maximum flow distortion shall be used. The flow distortion due to mounting effects (boom and mast effects) might be considerable unless the anemometer is mounted on a tube on top of the mast. The uncertainty of the anemometer calibration and the uncertainty due to operational characteristics (over-speeding, cosine response, sensitivity to temperature and air density) might be dominating in the measurement.

The category B uncertainty from wind speed in bin i, $u_{V,\mathrm{i}}$, can be expressed as:

$$u_{V,\mathrm{i}} = \sqrt{u_{V1,\mathrm{i}}^2 + u_{V2,\mathrm{i}}^2 + u_{V3,\mathrm{i}}^2 + u_{V4,\mathrm{i}}^2 + u_{dV,\mathrm{i}}^2} \tag{D.19}$$

where

$u_{V1,\mathrm{i}}$ is the uncertainty of the anemometer calibration in bin i;

$u_{V2,\mathrm{i}}$ is the uncertainty due to operational characteristics of the anemometer in bin i;

$u_{V3,\mathrm{i}}$ is the uncertainty of flow distortion due to mounting effects in bin i;

$u_{V4,\mathrm{i}}$ is the uncertainty of flow distortion due to the terrain in bin i;

$u_{dV,\mathrm{i}}$ is the uncertainty in the data acquisition system for the wind speed in bin i.

The sensitivity factor is determined as the local slope of the measured power curve:

$$c_{V,\mathrm{i}} = \frac{P_\mathrm{i} - P_{\mathrm{i}-1}}{V_\mathrm{i} - V_{\mathrm{i}-1}} \tag{D.20}$$

The standard uncertainty of the anemometer calibration is estimated to be 0,2 m/s. Uncertainty due to operational characteristics of the anemometer is estimated to be 0,5 % of the wind speed. The standard uncertainty of the flow distortion due to mounting effects is estimated to be 1 % of the wind speed, and the flow distortion due to the terrain is estimated to be 3 % of the wind speed. Considering a wind speed range of 30 m/s of the measurement channel and an uncertainty of the data acquisition system of 0,1 % of this range, the standard uncertainty from wind speed in each bin is:

$$\begin{aligned} u_{V,\mathrm{i}} &= \sqrt{(0{,}2\,\mathrm{m/s})^2 + (0{,}5\,\% \cdot V_\mathrm{i}[\mathrm{m/s}])^2 + (1\% \cdot V_\mathrm{i}[\mathrm{m/s}])^2 + (3\% \cdot V_\mathrm{i}[\mathrm{m/s}])^2 + (0{,}1\% \cdot 30\,\mathrm{m/s})^2} \\ &= \sqrt{(3{,}2\% \cdot V_\mathrm{i}[\mathrm{m/s}])^2 + (0{,}20\,\mathrm{m/s})^2} \end{aligned} \quad \text{(D.21)}$$

Category B uncertainties in air density

The air density is derived from measurements of the air temperature and the air pressure.

The measurement of the air temperature might include the following uncertainty components:

- uncertainty of the temperature sensor calibration;
- uncertainty due to imperfect radiation shielding of the temperature sensor (bad shielding raises the temperature at the sensor);
- uncertainty due to mounting effects (vertical air temperature profile variations from day to night influence the estimate of temperature if the temperature sensor is not at hub height).

The standard uncertainty in measured air temperature for each bin, $u_{T,\mathrm{i}}$, can be expressed as:

$$u_{T,\mathrm{i}} = \sqrt{u_{T1,\mathrm{i}}^2 + u_{T2,\mathrm{i}}^2 + u_{T3,\mathrm{i}}^2 + u_{dT,\mathrm{i}}^2} \quad \text{(D.22)}$$

where

$u_{T1,\mathrm{i}}$ is the uncertainty of temperature sensor calibration in bin i;

$u_{T2,\mathrm{i}}$ is the uncertainty due to imperfect radiation shielding of temperature sensor in bin i;

$u_{T3,\mathrm{i}}$ is the uncertainty due to mounting effects of temperature sensor in bin i;

$u_{dT,\mathrm{i}}$ are the uncertainties in data acquisition system for the air temperature in bin i.

The sensitivity factor for the air temperature measurement is, for sea-level conditions, estimated by:

$$c_{T,\mathrm{i}} \approx \frac{P_\mathrm{i}}{288{,}15} \ [\mathrm{kW\ /\ K}] \quad \text{(D.23)}$$

The measurement of the air pressure sensor might include first a correction factor to correct the air pressure to hub height if the sensor is not positioned at hub height. An uncertainty due to the correction might be considered, and the uncertainty (calibration) of the pressure sensor shall be included. The standard uncertainty in measured air pressure for each bin, $u_{B,\mathrm{i}}$, is:

$$u_{B,\mathrm{i}} = \sqrt{u_{B1,\mathrm{i}}^2 + u_{B2,\mathrm{i}}^2 + u_{dB,\mathrm{i}}^2} \quad \text{(D.24)}$$

where

$u_{B1,\mathrm{i}}$ is the uncertainty of air pressure sensor calibration in bin i;

$u_{B2,\mathrm{i}}$ is the uncertainty due to mounting effects of air pressure sensor in bin i;

$u_{dB,\mathrm{i}}$ are the uncertainties in data acquisition system for the air pressure in bin i.

The sensitivity factor for the air pressure measurement is, for sea level conditions, estimated by:

$$c_{B,\mathrm{i}} \approx \frac{P_\mathrm{i}}{1\ 013}\ [\mathrm{kW\ /\ hPa}] \tag{D.25}$$

The uncertainty due to the relative humidity might be significant if the average air temperature is high. At sea level and at an air temperature of 20 °C the air density varies 1,2 % between 0 % and 100 % relative humidity. It varies 2,0 % and 4,0 % at 30 °C and 40 °C, respectively. Thus, at high temperatures it is recommended to measure the relative humidity and to correct for it. The influence of the relative humidity is not taken into account in this example.

The standard uncertainty of the temperature sensor is assumed to be 0,5 °C. The shielding of the temperature sensor is assumed to produce a standard uncertainty of 2 °C. The standard uncertainty due to mounting effects of the temperature sensor is dependent on the vertical distance from the hub height. Above 10 m a standard uncertainty of 1/3 °C per 10 m from hub height is assumed, and if mounted below 10 m, an additional standard uncertainty of 1 °C is assumed. With the sensor at a level of 2 m above ground and a hub height of 30 m, the standard uncertainty due to mounting effects is 1,9 °C. Considering a temperature range of 40 °C of the measurement channel and an uncertainty of the data acquisition system of 0,1 % of this range, the expression for the standard uncertainty of the air temperature in each bin is:

$$u_{T,\mathrm{i}} = \sqrt{(0{,}5\ \mathrm{K})^2 + (2{,}0\ \mathrm{K})^2 + (1{,}9\ \mathrm{K})^2 + (0{,}1\ \% \cdot 40\ \mathrm{K})^2} = 2{,}8\ \mathrm{K} \tag{D.26}$$

The pressure sensor is estimated to have a standard uncertainty of 3,0 hPa. It is assumed that the pressure is corrected to the hub height according to ISO 2533 (which, for a standard atmosphere and a height difference of 28 m between the sensor and the hub, is 3,4 hPa). The uncertainty due to deployment is estimated to be 10 % of the correction, which is 0,34 hPa. Considering a pressure range of 100 hPa of the measurement channel and an uncertainty of the data acquisition system of 0,1 % of this range, the expression for the standard uncertainty of the air pressure is:

$$u_{B,\mathrm{i}} = \sqrt{(3{,}0\ \mathrm{hPa})^2 + (0{,}34\ \mathrm{hPa})^2 + (0{,}1\ \% \cdot 100\ \mathrm{hPa})^2} = 3{,}0\ \mathrm{hPa} \tag{D.27}$$

Combined category B uncertainties

The category B uncertainties in each bin are combined as:

$$\begin{aligned} u_\mathrm{i} &= \sqrt{u_{P,\mathrm{i}}^2 + c_{V,\mathrm{i}}^2\, u_{V,\mathrm{i}}^2 + c_{T,\mathrm{i}}^2\, u_{T,\mathrm{i}}^2 + c_{B,\mathrm{i}}^2\, u_{B,\mathrm{i}}^2} \\ &= \sqrt{(1{,}14\% \cdot P_\mathrm{i}\ [\mathrm{kW}])^2 + (6{,}3\ \mathrm{kW})^2 + c_{V,\mathrm{i}}^2((3{,}2\% \cdot V_\mathrm{i}\ [\mathrm{m/s}])^2 + (0{,}20\,\mathrm{m/s})^2)} \end{aligned} \tag{D.28}$$

Combined standard uncertainty – Power curve

The combined standard uncertainties of each bin of the power curve are found by combining the category A uncertainty with all the category B uncertainties.

$$\begin{aligned} u_{c,\mathrm{i}} &= \sqrt{s_\mathrm{i}^2 + u_\mathrm{i}^2} = \sqrt{s_{P,\mathrm{i}}^2 + u_{P,\mathrm{i}}^2 + c_{V,\mathrm{i}}^2 u_{V,\mathrm{i}}^2 + c_{T,\mathrm{i}}^2 u_{T,\mathrm{i}}^2 + c_{B,\mathrm{i}}^2 u_{B,\mathrm{i}}^2} \\ &= \sqrt{s_{P,\mathrm{i}}^2 + (1{,}14\,\% \cdot P_\mathrm{i}\,[\mathrm{kW}])^2 + (6{,}3\,\mathrm{kW})^2 + c_{V,\mathrm{i}}^2\left((3{,}2\,\% \cdot V_\mathrm{i}\,[\mathrm{m/s}])^2 + (0{,}20\,\mathrm{m/s})^2\right)} \end{aligned} \tag{D.29}$$

Combined standard uncertainty – Energy production

The combined standard uncertainty of *AEP* is found by combining individually the category A and B uncertainties bin-wise:

$$u_{AEP} = N_h \sqrt{\sum_{i=1}^{N} f_i^2\, s_i^2 + \left(\sum_{i=1}^{N} f_i\, u_i\right)^2}$$

$$= N_h \sqrt{\sum_{i=1}^{N} f_i^2\, s_{P,i}^2 + \left(\sum_{i=1}^{N} f_i \sqrt{(1{,}14\ \% \cdot P_i\,[\mathrm{kW}])^2 + (6{,}3\ \mathrm{kW})^2 + c_{V,i}^2\left((3{,}2\ \% \cdot V_i[\mathrm{m/s}])^2 + (0{,}20\ \mathrm{m/s})^2\right)}\right)^2} \quad \text{(D.30)}$$

Table D.3 – Sensitivity factors

	Power curve		Sensitivity factors		
Bin No. **i**	**Wind speed** V_i ms^{-1}	**Electric power** P_i kW	**Wind speed** $\alpha_{V,i}$ kW/ms^{-1}	**Air temperature** $\alpha_{T,i}$ kW/K	**Air pressure** $\alpha_{B,i}$ kW/hPa
1	1,59	–0,85	–1,71	0,00	0,00
2	2,02	–0,74	0,26	0,00	0,00
3	2,51	–0,81	–0,14	0,00	0,00
4	3,04	–0,50	0,57	0,00	0,00
5	3,53	–0,67	–0,33	0,00	0,00
6	4,04	0,16	1,60	0,00	0,00
7	4,55	7,32	14,15	0,03	0,01
8	4,99	25,89	41,94	0,09	0,03
9	5,54	61,43	64,60	0,21	0,06
10	6,00	93,16	68,84	0,32	0,09
11	6,47	129,78	79,25	0,45	0,13
12	6,97	174,46	88,47	0,61	0,17
13	7,53	231,77	103,46	0,80	0,23
14	8,02	283,63	103,93	0,98	0,28
15	8,51	339,55	113,87	1,18	0,34
16	9,00	387,22	98,50	1,34	0,38
17	9,51	445,98	115,67	1,55	0,44
18	9,99	504,41	120,47	1,75	0,50
19	10,50	565,17	119,84	1,96	0,56
20	11,01	620,67	107,78	2,15	0,61
21	11,50	680,87	124,37	2,36	0,67
22	12,02	731,22	96,45	2,54	0,72
23	12,46	770,77	89,68	2,67	0,76
24	13,03	820,11	86,27	2,85	0,81
25	13,53	850,86	62,13	2,95	0,84
26	13,99	884,94	73,13	3,07	0,87
27	14,47	923,82	81,68	3,21	0,91
28	14,98	940,46	32,89	3,26	0,93
29	15,49	956,59	31,44	3,32	0,94
30	15,92	972,27	36,74	3,37	0,96
31	16,50	990,54	31,49	3,44	0,98
32	16,93	994,74	9,75	3,45	0,98
33	17,45	987,43	–14,09	3,43	0,97
34	18,01	976,59	–19,21	3,39	0,96
35	18,51	980,11	7,07	3,40	0,97
36	18,91	984,33	10,51	3,42	0,97
37	19,50	954,56	–50,46	3,31	0,94
38	20,01	975,12	40,31	3,38	0,96
39	20,53	934,42	–78,58	3,24	0,92
40	20,97	952,60	40,87	3,31	0,94

Table D.4 – Category B uncertainties

Bin no. i	Electric power $u_{P,i}$ kW	Wind speed $u_{V,i}$ ms^{-1}	$\alpha_{V,i} \times u_{V,i}$ kW	Air temperature $u_{T,i}$ K	$\alpha_{T,i} \times u_{T,i}$ kW	Air pressure $u_{B,i}$ hPa	$\alpha_{B,i} \times u_{B,i}$ kW
1	6,30	0,21	–0,35	2,80	–0,01	3,00	0,00
2	6,30	0,21	0,06	2,80	–0,01	3,00	0,00
3	6,30	0,22	–0,03	2,80	–0,01	3,00	0,00
4	6,30	0,22	0,13	2,80	0,00	3,00	0,00
5	6,30	0,23	–0,08	2,80	–0,01	3,00	0,00
6	6,30	0,24	0,38	2,80	0,00	3,00	0,00
7	6,30	0,25	3,50	2,80	0,07	3,00	0,02
8	6,30	0,26	10,74	2,80	0,25	3,00	0,08
9	6,31	0,27	17,27	2,80	0,60	3,00	0,18
10	6,32	0,28	19,09	2,80	0,91	3,00	0,28
11	6,34	0,29	22,81	2,80	1,26	3,00	0,38
12	6,36	0,30	26,51	2,80	1,70	3,00	0,52
13	6,41	0,31	32,39	2,80	2,25	3,00	0,69
14	6,47	0,33	33,83	2,80	2,76	3,00	0,84
15	6,54	0,34	38,49	2,80	3,30	3,00	1,01
16	6,61	0,35	34,54	2,80	3,76	3,00	1,15
17	6,71	0,36	42,11	2,80	4,33	3,00	1,32
18	6,82	0,38	45,43	2,80	4,90	3,00	1,49
19	6,95	0,39	46,86	2,80	5,49	3,00	1,67
20	7,08	0,41	43,68	2,80	6,03	3,00	1,84
21	7,23	0,42	52,08	2,80	6,62	3,00	2,02
22	7,36	0,43	41,81	2,80	7,11	3,00	2,17
23	7,47	0,45	40,01	2,80	7,49	3,00	2,28
24	7,61	0,46	39,90	2,80	7,97	3,00	2,43
25	7,70	0,48	29,63	2,80	8,27	3,00	2,52
26	7,80	0,49	35,86	2,80	8,60	3,00	2,62
27	7,92	0,50	41,20	2,80	8,98	3,00	2,74
28	7,98	0,52	17,08	2,80	9,14	3,00	2,79
29	8,03	0,53	16,80	2,80	9,30	3,00	2,83
30	8,08	0,55	20,10	2,80	9,45	3,00	2,88
31	8,14	0,56	17,77	2,80	9,63	3,00	2,93
32	8,15	0,58	5,63	2,80	9,67	3,00	2,95
33	8,13	0,59	–8,36	2,80	9,59	3,00	2,92
34	8,09	0,61	–11,72	2,80	9,49	3,00	2,89
35	8,10	0,63	4,42	2,80	9,52	3,00	2,90
36	8,12	0,64	6,70	2,80	9,56	3,00	2,92
37	8,02	0,66	–33,06	2,80	9,28	3,00	2,83
38	8,09	0,67	27,04	2,80	9,48	3,00	2,89
39	7,96	0,69	–53,95	2,80	9,08	3,00	2,77
40	8,01	0,70	28,62	2,80	9,26	3,00	2,82

Annex E
(informative)

Bibliography

The following standards can be relevant to the use of this standard:

IEC 61400-1:1994, *Wind turbine generator systems – Part 1: Safety requirements*

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

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- ☐ corporate
- ☐ other (published by...................)
- ☐ other (published by...................)
- ☐ other (published by...................)

6.

This standard meets my needs (check one)

- ☐ not at all
- ☐ almost
- ☐ fairly well
- ☐ exactly

7.

Please rate the standard in the following areas as (1) bad, (2) below average, (3) average, (4) above average, (5) exceptional, (0) not applicable:

- ☐ clearly written
- ☐ logically arranged
- ☐ information given by tables
- ☐ illustrations
- ☐ technical information

8.

I would like to know how I can legally reproduce this standard for:

- ☐ internal use
- ☐ sales information
- ☐ product demonstration
- ☐ other................................

9.

In what medium of standard does your organization maintain most of its standards (check one):

- ☐ paper
- ☐ microfilm/microfiche
- ☐ mag tapes
- ☐ CD-ROM
- ☐ floppy disk
- ☐ on line

9A.

If your organization currently maintains part or all of its standards collection in electronic media, please indicate the format(s):

- ☐ raster image
- ☐ full text

10.

In what medium does your organization intend to maintain its standards collection in the future (check all that apply):

- ☐ paper
- ☐ microfilm/microfiche
- ☐ mag tape
- ☐ CD-ROM
- ☐ floppy disk
- ☐ on line

10A.

For electronic media which format will be chosen (check one)

- ☐ raster image
- ☐ full text

11.

My organization is in the following sector (e.g. engineering, manufacturing)

....

12.

Does your organization have a standards library:

- ☐ yes
- ☐ no

13.

If you said yes to 12 then how many volumes:

....

14.

Which standards organizations published the standards in your library (e.g. ISO, DIN, ANSI, BSI, etc.):

....

15.

My organization supports the standards-making process (check as many as apply):

- ☐ buying standards
- ☐ using standards
- ☐ membership in standards organization
- ☐ serving on standards development committee
- ☐ other................................

16.

My organization uses (check one)

- ☐ French text only
- ☐ English text only
- ☐ Both English/French text

17.

Other comments:

....

....

....

....

....

....

18.

Please give us information about you and your company

name: ....

job title:...

company: ....

address:..

....

....

....

No. employees at your location:.........

turnover/sales:.................................

Publications de la CEI préparées par le Comité d'Etudes n° 88

61400:— Aérogénérateurs.

61400-1 (1994) Partie 1: Spécifications de sécurité.

61400-2 (1996) Partie 2: Sécurité des petits aérogénérateurs.

61400-12 (1998) (Publiée en langue anglaise uniquement)

IEC publications prepared by Technical Committee No. 88

61400. — Wind turbine generator systems.

61400-1 (1994) Part 1: Safety requirements.

61400-2 (1996) Part 2: Safety of small wind turbines.

61400-12 (1998) Part 12: Wind turbine power performance testing.

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