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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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.
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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	[m²]
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.

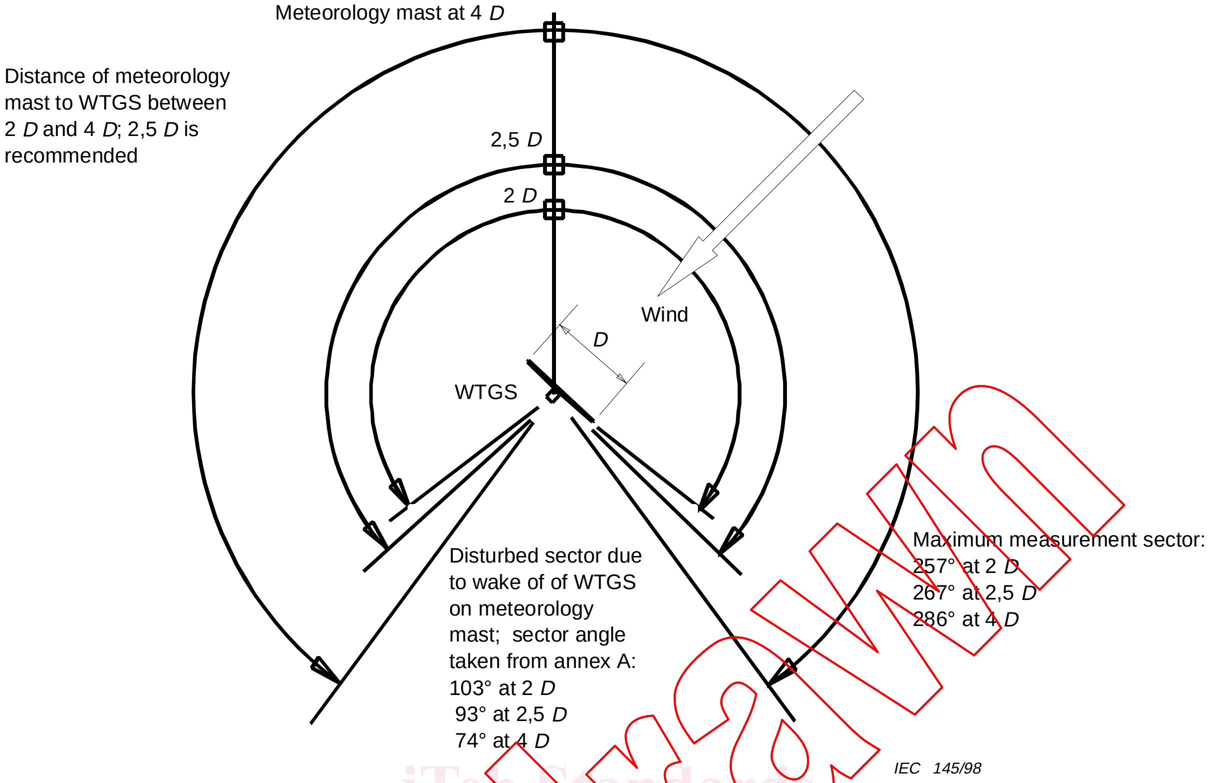

Figure 1 – Requirements as to distance of the meteorological mast and maximum allowed measurement sectors

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.