

INTERNATIONAL STANDARD

NORME INTERNATIONALE



Wind turbines –

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

Eoliennes –

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

This is a preview. [Click here to purchase the full publication.](#)



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2013 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester.

If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de la CEI ou du Comité national de la CEI du pays du demandeur.

Si vous avez des questions sur le copyright de la CEI ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de la CEI de votre pays de résidence.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

Useful links:

IEC publications search - www.iec.ch/searchpub

The advanced search enables you to find IEC publications by a variety of criteria (reference number, text, technical committee,...).

It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available on-line and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary (IEV) on-line.

Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

A propos de la CEI

La Commission Electrotechnique Internationale (CEI) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications CEI

Le contenu technique des publications de la CEI est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Liens utiles:

Recherche de publications CEI - www.iec.ch/searchpub

La recherche avancée vous permet de trouver des publications CEI en utilisant différents critères (numéro de référence, texte, comité d'études,...).

Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

Just Published CEI - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications de la CEI. Just Published détaille les nouvelles publications parues. Disponible en ligne et aussi une fois par mois par email.

Electropedia - www.electropedia.org

Le premier dictionnaire en ligne au monde de termes électroniques et électriques. Il contient plus de 30 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans les langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (VEI) en ligne.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: csc@iec.ch.

INTERNATIONAL STANDARD

NORME INTERNATIONALE



Wind turbines –

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

Eoliennes –

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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX

XE

ICS 27.180

ISBN 978-2-83220-658-4

Warning! Make sure that you obtained this publication from an authorized distributor.

Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 Scope.....	8
2 Normative references	8
3 Terms and definitions	9
4 Symbols and units	13
5 Overview of test method	16
6 Preparation for performance test	19
6.1 General.....	19
6.2 Wind turbine.....	19
6.3 Test site	19
6.3.1 Terrain classification.....	20
6.3.2 RIX indices	20
6.3.3 Average slope	21
6.3.4 Determine terrain class.....	21
6.3.5 Ridge formations	22
6.4 Nacelle wind speed transfer function	23
6.5 Test plan	23
7 Test equipment.....	23
7.1 Electric power	23
7.2 Wind speed	24
7.3 Wind direction	24
7.3.1 Nacelle yaw position sensor	24
7.3.2 Nacelle wind direction sensor	25
7.3.3 Wind direction	25
7.4 Air density	25
7.5 Rotor speed	26
7.6 Pitch angle	26
7.7 Wind turbine status	26
7.8 Data acquisition.....	26
8 Measurement procedure.....	27
8.1 General.....	27
8.2 Wind turbine operation	27
8.3 Data system(s) synchronisation.....	27
8.4 Data collection	28
8.5 Data quality check.....	28
8.6 Data rejection.....	29
8.7 Data correction.....	30
8.8 Database.....	30
9 Derived results	31
9.1 Data normalisation	31
9.1.1 Density correction.....	31
9.2 Determination of measured power curve.....	32
9.3 Annual energy production (AEP).....	32
9.4 Power coefficient.....	33
9.5 Uncertainty analysis	34

10 Reporting format.....	34
Annex A (informative) Nacelle instrument mounting	42
Annex B (normative) Measurement sector procedure	44
Annex C (normative) Nacelle wind speed transfer function validity procedure	49
Annex D (normative) Nacelle wind speed transfer function measurement procedure	51
Annex E (normative) Evaluation of uncertainty in measurement	58
Annex F (normative) Theoretical basis for determining the uncertainty of measurement using the method of bins	62
Annex G (normative) NTF/NPC uncertainty estimates and calculation.....	70
Annex H (normative) Allowable anemometry instrument types	83
Annex I (informative) Results and uncertainty considerations.....	85
Annex J (informative) Example multi-turbine NTF/NPC uncertainty calculation.....	90
Annex K (informative) Organisation of test, safety and communication.....	98
Annex L (informative) NPC and NTF flowchart	100
Figure 1 – Procedural overview.....	18
Figure 2 – Presentation of example data: transfer function resulting from Annex D	37
Figure 3 – Presentation of example data: nacelle power performance test scatter plots	38
Figure 4 – Presentation of example data: binned power curve with uncertainty bands	38
Figure 5 – Presentation of example data: measured power curve and C_p curve	39
Figure A.1 – Mounting of anemometer on top of nacelle.....	43
Figure B.1 – Sectors to exclude due to wakes of neighbouring and operating wind turbines and significant obstacles	46
Figure B.2 – Example of the result of a sector self-consistency check.....	48
Figure D.1 – Nacelle transfer function for wind speed	56
Figure J.1 – Impact of multiple turbine testing on measurement uncertainty	97
Figure J.2 – Impact of multiple turbine testing on sampling uncertainty	97
Figure L.1 – NPC flowchart	100
Figure L.2 – NTF flowchart.....	101
Table 1 – Slope terrain classification	21
Table 2 – RIX terrain classification.....	22
Table 3 – Final terrain class.....	22
Table 4 – Maximum ridge step effects on terrain class	22
Table 5 – Example of a measured power curve	40
Table 6 – Example of estimated annual energy production.....	41
Table B.1 – Obstacle requirements: relevance of obstacles	45
Table D.1 – Example of presentation of a measured power curve based on data from the meteorological mast, for consistency check	57
Table E.1 – Uncertainty components in nacelle transfer function evaluation.....	59
Table E.2 – Uncertainty components in nacelle power curve evaluation	60
Table E.3 – Uncertainty components in nacelle based absolute wind direction	61
Table F.1 – Example cancellation sources	64
Table F.2 – List of category A and B uncertainties for NTF	64

Table F.3 – List of category A and B uncertainties for NPC	66
Table F.4 – Expanded uncertainties	69
Table G.1 – Estimates for uncertainty components from site calibration	70
Table G.2 – Estimates for uncertainty components from NTF measurement	72
Table G.3 – Estimates for uncertainty components from NPC measurement	74
Table G.4 – Estimates for $u_{V5,i}$ for NPC terrain class	76
Table G.5 – Estimates for uncertainty components for wind direction	77
Table G.6 – Estimates for contribution factors for site calibration	78
Table G.7 – Estimates for contribution factors for NTF	79
Table G.8 – Estimates for contribution factors for NPC	80
Table J.1 – List of correlated uncertainty components	91
Table J.2 – Sample AEP and uncertainty data from 3 turbines	93
Table J.3 – Component uncertainty contribution to AEP uncertainty on turbine 1	93
Table J.4 – Combination of uncertainty components across turbines	95

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND TURBINES –

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

FOREWORD

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

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

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

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

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

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

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

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

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

The purpose of this part of IEC 61400-12 is to provide a uniform methodology of measurement, analysis, and reporting of power performance characteristics for individual electricity-producing wind turbines utilising nacelle-anemometry methods. This standard is intended to be applied only to horizontal axis wind turbines of sufficient size that the nacelle-mounted anemometer does not significantly affect the flow through the turbine's rotor and around the nacelle and hence does not affect the wind turbine's performance. The intent of this standard is that the methods presented herein be utilised when the requirements set forth in IEC 61400-12-1:2005 are not feasible. This will ensure that the results are as consistent, accurate, and reproducible as possible within the current state of the art for instrumentation and measurement techniques.

This procedure describes how to characterise a wind turbine's power performance characteristics in terms of a measured power curve and the estimated annual energy production (AEP) based on nacelle-anemometry. In this procedure, the anemometer is located on or near the test turbine's nacelle. In this location, the anemometer is measuring wind speed that is strongly affected by the test turbine's rotor. This procedure includes methods for determining and applying appropriate corrections for this interference. However, it must be noted that these corrections inherently increase the measurement uncertainty compared to a properly-configured test conducted in accordance with IEC 61400-12-1:2005. The procedure also provides guidance on determination of measurement uncertainty including assessment of uncertainty sources and recommendations for combining them into uncertainties in reported power and AEP.

A key element of power performance testing is the measurement of wind speed. Even when anemometers are carefully calibrated in a quality wind tunnel, fluctuations in magnitude and direction of the wind vector can cause different anemometers to perform differently in the field. Further, the flow conditions close to a turbine nacelle are complex and variable. Therefore special care should be taken in the selection and installation of the anemometer. These issues are addressed in this standard.

The standard will benefit those parties involved in the manufacture, installation, planning and permitting, operation, utilisation and regulation of wind turbines. When appropriate, the technically accurate measurement and analysis techniques recommended in this standard should be applied by all parties to ensure that continuing development and operation of wind turbines is carried out in an atmosphere of consistent and accurate communication relative to environmental concerns. This standard presents measurement and reporting procedures expected to provide accurate results that can be replicated by others.

Meanwhile, a user of the standard should be aware of differences that arise from large variations in wind shear and turbulence intensity, and from the chosen criteria for data selection. Therefore, a user should consider the influence of these differences and the data selection criteria in relation to the purpose of the test before contracting power performance measurements.

WIND TURBINES –

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

1 Scope

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

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

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

2 Normative references

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

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

Amendment 1 (1997)

Amendment 2 (2001)

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

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

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

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

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

ISO 2533, *Standard atmosphere*

3 Terms and definitions

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

3.1

accuracy

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

3.2

annual energy production (AEP)

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

3.3

annual energy production – measured (AEP-measured)

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

3.4

annual energy production – extrapolated (AEP-extrapolated)

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

3.5

complex terrain

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

3.6

data set

collection of data that was sampled over a contiguous period