

INTERNATIONAL STANDARD

NORME INTERNATIONALE



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

**Systèmes de génération d'énergie éolienne –
Partie 50-3: Utilisation de lidars montés sur nacelle pour le mesurage du vent**





THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2022 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 l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

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

Tel.: +41 22 919 02 11
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 corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform

The advanced search enables 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 It also gives information on projects, replaced and withdrawn publications.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 online and once a month by email.

IEC 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: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch

Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org

The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

A propos de l'IEC

La Commission Electrotechnique Internationale (IEC) 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 IEC

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

Recherche de publications IEC - webstore.iec.ch/advsearchform

La recherche avancée permet de trouver des publications IEC 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.

IEC Just Published - webstore.iec.ch/justpublished

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

Service Clients - webstore.iec.ch/csc

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

IEC Products & Services Portal - products.iec.ch

Découvrez notre puissant moteur de recherche et consultez gratuitement tous les aperçus des publications. Avec un abonnement, vous aurez toujours accès à un contenu à jour adapté à vos besoins.

Electropedia - www.electropedia.org

Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 300 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 19 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

INTERNATIONAL STANDARD

NORME INTERNATIONALE



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

**Systèmes de génération d'énergie éolienne –
Partie 50-3: Utilisation de lidars montés sur nacelle pour le mesurage du vent**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 27.180

ISBN 978-2-8322-1063-9

**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.....	6
1 Scope.....	8
2 Normative references	8
3 Terms and definitions	9
4 Symbols and abbreviated terms.....	14
5 Overview	18
5.1 General.....	18
5.2 Measurement methodology overview	19
5.3 Document overview.....	20
6 Lidar requirements.....	20
6.1 Functional requirements.....	20
6.2 Documentary requirements	21
6.2.1 Technical documentation	21
6.2.2 Installation and operation documentation.....	22
7 Calibration and uncertainty of nacelle lidar intermediate values	22
7.1 Calibration method overview	22
7.2 Verification of beam trajectory/geometry	23
7.2.1 Static position uncertainty.....	23
7.2.2 Dynamic position uncertainty	24
7.3 Inclinometer calibration	24
7.4 Verification of the measurement range	24
7.5 LOS speed calibration.....	25
7.5.1 Method overview	25
7.5.2 Calibration site requirements	26
7.5.3 Setup requirements	28
7.5.4 Calibration range	30
7.5.5 Calibration data requirements and filtering.....	30
7.5.6 Determination of LOS	31
7.5.7 Binning of data and database requirements	33
7.6 Uncertainty of the LOS speed measurement	33
7.6.1 General	33
7.6.2 Uncertainty of V_{ref}	34
7.6.3 Flow inclination uncertainty.....	37
7.6.4 Uncertainty of the LOS speed measurement	37
7.7 Calibration results.....	38
7.8 Calibration reporting requirements	39
7.8.1 Report content.....	39
7.8.2 General lidar information	40
7.8.3 Verification of beam geometry/trajectory (according to 7.2).....	40
7.8.4 Inclinometer calibration (according to 7.3)	40
7.8.5 Verification of the sensing range (according to 7.4)	40
7.8.6 LOS speed calibration (for each LOS).....	40
8 Uncertainty due to changes in environmental conditions	41
8.1 General.....	41
8.2 Intermediate value uncertainty due to changes in environmental conditions	41
8.2.1 Documentation	41

8.2.2	Method	41
8.2.3	List of environmental variables to be considered	42
8.2.4	Significance of uncertainty contribution	42
8.3	Evidence-base supporting the adequacy of the WFR	42
8.4	Requirements for reporting	43
9	Uncertainty of reconstructed wind parameters	44
9.1	Horizontal wind speed uncertainty	44
9.2	Uncertainty propagation through WFR algorithm	45
9.2.1	Propagation of intermediate value uncertainties $u_{\langle V \rangle, WFR}$	45
9.2.2	Uncertainties of other WFR parameters $u_{WFR, par}$	46
9.3	Uncertainty associated with the WFR algorithm $u_{ope, lidar}$	46
9.4	Uncertainty due to varying measurement height $u_{\langle \Delta V \rangle, measHeight}$	46
9.5	Uncertainty due to lidar measurement inconsistency	46
9.6	Combining uncertainties	47
10	Preparation for specific measurement campaign	47
10.1	Overview of procedure	47
10.2	Pre-campaign check list	47
10.3	Measurement set up	48
10.3.1	Lidar installation	48
10.3.2	Other sensors	48
10.3.3	Nacelle position calibration	49
10.4	Measurement sector	49
10.4.1	General	49
10.4.2	Assessment of influence from surrounding WTGs and obstacles	49
10.4.3	Terrain assessment	52
11	Measurement procedure	53
11.1	General	53
11.2	WTG operation	53
11.3	Consistency check of valid measurement sector	54
11.4	Data collection	55
11.5	Data rejection	56
11.6	Database	56
11.7	Application of WFR algorithm	56
11.8	Measurement height variations	57
11.9	Lidar measurement monitoring	57
12	Reporting format – relevant tables and figures specific to nacelle-mounted lidars	57
12.1	General	57
12.2	Specific measurement campaign site description	57
12.3	Nacelle lidar information	58
12.4	WTG information	58
12.5	Database	58
12.6	Plots	59
12.7	Uncertainties	59
Annex A (informative)	Example calculation of uncertainty of reconstructed parameters for WFR with two lines of sight	60
A.1	Introduction to example case	60
A.2	Uncertainty propagation through WFR algorithm	61
A.3	Operational uncertainty of the lidar and WFR algorithm	63

A.4	Uncertainty contributions from variation of measurement height.....	63
A.5	Wind speed consistency check.....	64
A.6	Combined uncertainty	64
Annex B (informative)	Suggested method for the measurement of tilt and roll angles.....	65
Annex C (informative)	Recommendation for installation of lidars on the nacelle	68
C.1	Positioning of lidar optical head on the nacelle.....	68
C.2	Lidar optical head pre-tilt for fixed beam lidars.....	69
C.3	Attachment points for the lidar	70
Annex D (informative)	Assessing the Influence of nacelle-mounted lidar on turbine behaviour.....	71
D.1	General.....	71
D.2	Recommended consistency checks methods.....	71
D.2.1	General	71
D.2.2	Documentation-based approach	71
D.2.3	Data-based approach using neighbouring WTG	72
D.2.4	Data-based approach using only the WTG being assessed.....	74
Bibliography	78
Figure 1	– Example of opening angle β between two beams	23
Figure 2	– Side elevation sketch of calibration setup.....	26
Figure 3	– Plan view sketch of sensing and inflow areas	27
Figure 4	– Sketch of a calibration setup	30
Figure 5	– Example of lidar response to the wind direction and cosine fit.....	32
Figure 6	– Example of LOS evaluation using the RSS process: RSS vs θ_{proj}	33
Figure 7	– High level process for horizontal wind speed uncertainty propagation	45
Figure 8	– Procedure flow chart	47
Figure 9	– Plan view sketch of NML beams upstream of WTG being assessed and neighbouring turbine wake	49
Figure 10	– Sectors to exclude due to wakes of neighbouring and operating WTGs and significant obstacles	51
Figure 11	– Example of sectors to exclude due to wakes of a neighbouring turbine and a significant obstacle	52
Figure 12	– Example of full directional sector discretization	53
Figure 13	– Lidar relative wind direction vs turbine yaw for a two-beam nacelle lidar [Wagner R, 2013].....	54
Figure 14	– Example of LOS turbulence intensity vs turbine yaw, for a two-beam nacelle lidar	55
Figure B.1	– Pair of tilted and rolled lidar beams (red) shown in relation to the reference position (grey).....	65
Figure B.2	– Opening angle between two beams symmetric with respect to the horizontal plane(γ) and its projection onto the vertical plane of symmetry of the lidar (γ_V)	67
Figure C.1	– Example of a good (left) and bad (right) position for a 2-beam lidar	68
Figure C.2	– Example of a good (left) and bad (right) position for a 4-beam lidar	68
Figure C.3	– Sketch of lidar optical head pre-tilted downwards to measure at hub height (example for a two beam lidar)	70
Figure D.1	– Example of reporting the side-by-side comparison	73

Figure D.2 – Example of the power ratio between two neighbouring turbines 74

Figure D.3 – General process outline 74

Figure D.4 – Example of binned ΔDir_{Nac} function for a setting where the lidar has not significantly influenced the two nacelle wind direction sensors' reported signals 77

Table 1 – Summary of calibration uncertainty components 38

Table 2 – Calibration table example 39

Table 3 – Calibration table example (n=1...N; N is the total number of lines of sight calibrated) 39

Table A.1 – Uncertainty components and their correlations between different LOSs for this example 62

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –

Part 50-3: Use of nacelle-mounted lidars for wind measurements

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 61400-50-3 has been prepared by IEC technical committee TC 88: Wind energy generation systems.

The text of this International Standard is based on the following documents:

Draft	Report on voting
88/845/FDIS	88/853/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

IMPORTANT – The 'colour inside' logo on the cover page of this 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.

WIND ENERGY GENERATION SYSTEMS –

Part 50-3: Use of nacelle-mounted lidars for wind measurements

1 Scope

The purpose of this part of IEC 61400 is to describe procedures and methods that ensure that wind measurements using nacelle-mounted wind lidars are carried out and reported consistently and according to best practice. This document does not prescribe the purpose or use case of the wind measurements. However, as this document forms part of the IEC 61400 series of standards, it is anticipated that the wind measurements will be used in relation to some form of wind energy test or resource assessment.

The scope of this document is limited to forward-looking nacelle-mounted wind lidars (i.e. the measurement volume is located upstream of the turbine rotor).

This document aims to be applicable to any type and make of nacelle-mounted wind lidar. The method and requirements provided in this document are independent of the model and type of instrument, and also of the measurement principle and should allow application to new types of nacelle-mounted lidar.

This document aims to describe wind measurements using nacelle-mounted wind lidar with sufficient quality for the use case of power performance testing (according to IEC 61400-12-1:2017). Readers of this document should consider that other use cases may have other specific requirements.

This document only provides guidance for measurements in flat terrain and offshore as defined in IEC 61400-12-1:2017, Annex B. Application to complex terrain has been excluded from the scope due to limited experience at the time of writing this document.

Corrections for induction zone or blockage effects are not included in the scope of this document. However, such correction or uncertainty estimation due to blockage effects may be applied if required by the use case, under the responsibility of the user.

The purpose of this document is to provide guidance for wind measurements. HSE requirements (e.g. laser operation) are out of the scope of this document although they are important.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 61400-12-1:2017, *Wind energy generation systems – Part 12-1: Power performance measurements of electricity producing wind turbines*

ISO/IEC 61400-12-2:2013, *Wind energy generation systems – Part 12-2: Power performance of electricity-producing wind turbines based on nacelle anemometry*