



# TECHNICAL REPORT

---

**Wind energy generation systems –  
Part 12-4: Numerical site calibration for power performance testing of wind  
turbines**

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

---

ICS 27.180

ISBN 978-2-8322-8781-1

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

## CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	7
2 Normative references .....	7
3 Terms, definitions, abbreviations and symbols.....	7
3.1 Abbreviations.....	7
3.2 Symbols and units.....	8
4 Overview of Numerical Flow Simulation Approaches.....	10
4.1 Linear Flow Models.....	10
4.2 Reynolds-averaged Navier-Stokes (RANS) Models .....	11
4.3 Large Eddy Simulation (LES) and Hybrid RANS/LES Models .....	12
5 Existing Guidelines for Numerical Flow Modelling Applications .....	13
5.1 General.....	13
5.2 AIAA (1998) Guide for the Verification and Validation of Computational Fluid Dynamics Simulations.....	14
5.3 Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer – ASME V&V 20-2009.....	14
5.4 COST Action 732 “Quality Assurance of Microscale Meteorological Models” .....	15
5.5 Architectural Institute of Japan Guidelines .....	16
5.5.1 General .....	16
5.5.2 The guidebook for practical applications of CFD to pedestrian wind environment around buildings [18] .....	16
5.5.3 Guidebook of recommendations for loads on buildings 2 [19].....	16
5.6 VDI 3783 Part 9 “Environmental meteorology – prognostic microscale wind field mode- evaluation of flow around buildings and obstacles” .....	16
5.7 International Energy Agency Task 31 Wakebench – Model Evaluation Protocol for Wind Farm Flow Models.....	17
5.8 MEASNET – Evaluation of Site-Specific Wind Conditions.....	17
6 Summary of Benchmarking Validation Tests .....	17
6.1 General.....	17
6.2 DEWI Round Robin on Numerical Flow Simulation in Wind Energy .....	17
6.3 Bolund Experiment.....	18
6.4 European Wind Energy Association Comparative Resource and Energy Yield Assessment Procedures I and II (2011, 2013).....	18
6.5 IEA Task 31 Wakebench Experiments.....	19
6.6 New European Wind Atlas Experiments [32] .....	19
6.6.1 Perdigão (double ridge) .....	19
6.6.2 Alaiz (complex terrain with a strong mesoscale component) .....	19
6.6.3 Østerild (flow over heterogeneous roughness) .....	19
6.6.4 Kassel (flow over forested hill).....	20
6.7 Wind Forecast Improvement Project 2 [34].....	20
6.8 Wind Tunnel Test Validation Data .....	20
6.8.1 Compilation of Experimental Data for Validation of Microscale Dispersion Models [23] .....	20
6.8.2 AIJ wind tunnel.....	20
6.8.3 Wind tunnel test for flow over hill .....	20

- 7 Important Technical Aspects for Performing Flow Simulations over Terrain for Wind Energy Applications ..... 21
  - 7.1 General..... 21
  - 7.2 Quality of Topographical Input Data ..... 21
  - 7.3 Computational Domain ..... 21
  - 7.4 Boundary Conditions for Computational Domain ..... 21
  - 7.5 Mesh Parameters..... 21
  - 7.6 Convergence Criteria ..... 21
  - 7.7 Atmospheric Stability ..... 21
  - 7.8 Coriolis Effects ..... 22
  - 7.9 Obstacles effects ..... 22
  - 7.10 Suggestion on Model Range Applicability for NSC ..... 22
- 8 Open Issues ..... 22
  - 8.1 General..... 22
  - 8.2 Determination of Flow Correction Factors from Numerical Simulation Results for Power Curve Testing ..... 23
    - 8.2.1 General ..... 23
    - 8.2.2 Correlation check for linear regression ..... 23
    - 8.2.3 Change in correction between adjacent wind direction bins ..... 23
    - 8.2.4 Site calibration and power performance measurements in different seasons ..... 23
  - 8.3 Uncertainty quantification..... 23
  - 8.4 Proposal for Validation Campaign for NSC Procedures ..... 24
    - 8.4.1 General ..... 24
    - 8.4.2 Assessment of terrain at the test site ..... 24
    - 8.4.3 Experimental layout ..... 24
- Bibliography..... 26
- Table 1 – symbols used in this Technical Report..... 8

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

**WIND ENERGY GENERATION SYSTEMS –****Part 12-4: Numerical site calibration for power  
performance testing of wind turbines**

## 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.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a Technical Report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 61400-12-4, which is a Technical Report, has been prepared by IEC technical committee 88: Wind energy generation systems.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
88/729/DTR	88/774/RVDTR

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

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

A list of all parts of the IEC 61400 series, under the general title *Wind energy generation systems*, can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://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.

## INTRODUCTION

IEC 61400-12-1 [1]<sup>1</sup> is the International Standard for power performance measurements for electricity producing wind turbines. It specifies that in complex terrain, a site calibration (SC) is required to find the relation in flow characteristics between the measurement location and the test turbine. This approach requires – in addition to the permanent measurement mast that is used to measure the turbine power curve – installing a temporary mast at the location of the turbine being tested, prior to the turbine installation. The IEC 61400-12-1 approach is frequently used in industrial practice; however, it has a number of disadvantages:

- additional cost of the second mast and analysis of the site calibration results,
- additional time required for the site calibration in the range of 3 months,
- a site calibration decision has to be made before installing the wind turbine.

Due to these disadvantages, there is interest in the industry to find alternative methods for site calibration. One alternative is to use numerical simulations to derive flow correction factors (FCFs), i.e., the relation between wind speed at the wind turbine position and wind speed at the reference meteorological mast position.

The IEC TC 88 committee, “Wind energy generation systems,” initiated the work on this document to evaluate the potential application of numerical flow simulations for site calibration, i.e., numerical site calibration (NSC).

With NSC, the flow correction factors are calculated using numerical simulation of the flow. Despite eliminating some of the disadvantages mentioned earlier, NSC brings other challenges:

- dependence on simulation models,
- dependence on the setup of these models,
- dependence on the modeler’s expertise,
- uncertainty quantification of the model performance.

The project team (PT 61400-12-4) has outlined the current state of the art in numerical flow modelling and has summarized existing guidelines and past benchmarking experience of numerical model validation and verification. Based on the work undertaken, the project team identified the important technical aspects for using flow simulations over terrain for wind energy applications as well as the existing open issues including recommendations for further validation through benchmarking tests. The project team concluded that further work is needed before a standard for NSC can be issued.

---

<sup>1</sup> Numbers in square brackets refer to the Bibliography.

## **WIND ENERGY GENERATION SYSTEMS –**

### **Part 12-4: Numerical site calibration for power performance testing of wind turbines**

#### **1 Scope**

This part of IEC 61400, which is a Technical Report, summarizes the current state of the art in numerical flow modelling, existing guidelines and past benchmarking experience in numerical model validation and verification. Based on the work undertaken, the document identifies the important technical aspects for using flow simulation over terrain for wind application as well as the existing open issues including recommendations for further validation through benchmarking tests.

#### **2 Normative references**

There are no normative references in this document.