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TECHNICAL REPORT

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

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WIND ENERGY GENERATION SYSTEMS –

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FOREWORD

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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- withdrawn,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][1] 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.

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[1] 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.

3 Terms, definitions, abbreviated terms and symbols

3.1 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.2 Abbreviated terms

The following abbreviated terms are used in this document.

AIAA	American Institute of Aeronautics and Astronautics
ABL	atmospheric boundary layer
AEP	annual energy production
AIJ	Architectural Institute of Japan
ALEX17	Alaiz experiment 2017
ASME	American Society of Mechanical Engineers
CEDVAL	Compilation and Experimental Data for Validation of Microscale DispersionModels
CFD	computational fluid dynamics
CHT	computational heat transfer
COST	European Cooperation in Science and Technology
CREYAP	Comparative Resource and Energy Yield Assessment Procedures
DES	detached eddy simulation
DDES	delayed detached eddy simulation
DEWI	Deutsches Windenergie-Institut

DTU	Danish Technical University
EWEA	European Wind Energy Association
EWTL	Environmental Wind Tunnel Laboratory
FCF	flow correction factor
GWh	gigawatt-hour
IEA	International Energy Agency
IEC	International Electrotechnical Commission
LES	large eddy simulation
LIDAR	light detection and ranging
MEASNET	Measuring Network of Wind Energy Institutes
MEP	model evaluation protocol
NEWA	New European Wind Atlas
NSC	numerical site calibration
RANS	Reynolds-averaged Navier-Stokes
RNG	renormalization group
SC	site calibration
SODAR	sound detection and ranging
TC	technical committee
TR	technical report
UQ	uncertainty quantification
URANS	unsteady Reynolds-averaged Navier-Stokes
V&V	verification and validation
VDI	Verein Deutscher Ingenieure
WAsP	Wind Atlas Analysis and Application Program
WFIP	Wind Forecast Improvement Project
WTG	wind turbine generator

3.3 Symbols and units

Table 1 shows the symbols used in the text and equations in this document.

Table 1 – Symbols used in this document

Symbol	Definition	Unit
$\overline{u}_i$	i th component of filtered wind speed	m/s
$\overline{p}$	filtered pressure	Pa
μ	molecular viscosity	Pa s
μ_t	turbulence viscosity	Pa s
C_s	Smagorinsky constant	-
κ	von Karman constant	-
d	distance to the nearest wall	m
Δ	local filter size	m
l	turbulence length scale	m

Symbol	Definition	Unit
l_{RANS}	turbulence length scale obtained from RANS model	m
l_{LES}	turbulence length scale obtained from LES model	m
f_{d}	model constant of DDES model	m
$\overline{U_i}$	average component of velocity in the direction i	m/s
u_i	turbulent component of velocity in the direction i	m/s
x_i	space variable in the direction i	m
$\overline{P}$	average pressure	Pa
ρ	density	kg/m^3
ν	kinematic molecular viscosity	m^2/s
$\overline{F_i}$	body forces in the direction i	kg m / s
$\overline{u_i u_j}$	Reynolds stresses	m^2/s^2
δ_{ij}	Kronecker's delta	-
ν_T	kinematic turbulence viscosity	m^2/s
k	turbulence kinetic energy	m^2/s^2
L_T	turbulence length scale	m
P_k	production of k	m^2/s^3
ε	dissipation rate of turbulence kinetic energy	m^2/s^3
C_μ	RANS turbulence model constant	-
$C_{1\varepsilon}$	RANS turbulence model constant	-
$C_{2\varepsilon}$	RANS turbulence model constant	-
σ_ε	RANS turbulence model constant	-
E	validation comparison error	
δ_{model}	error due to the modelling assumptions	
δ_{num}	error due to numerical solution of the equations	
δ_{input}	error due to input parameters	
δ_{D}	error in the experimental values	
u_{val}	validation standard uncertainty	
u_{num}	numerical solution uncertainty	
u_{input}	input parameters uncertainty	
u_D	experimental value uncertainty	
r	correlation coefficient	-
γ_d	DDES parameter	-

Symbol	Definition	Unit
A_1	modified DDES constant / stepwise function	-
A_2	DDES constant	-
K_h	effective horizontal kinematic viscosity	$\mathrm{m^2/s}$
K_v	effective vertical kinematic viscosity	$\mathrm{m^2/s}$
$\tilde{u}_i$	velocity perturbation components in the direction i	m/s
$\tilde{p}$	pressure perturbation	Pa
U_j	horizontal velocity components of the unperturbed flow in the direction j	m/s
D	rotor diameter	m

4 Overview of numerical flow simulation approaches

4.1 Linear flow models

Since the late 1980s, when computing resources were limited, linear wind flow models have been the standard for wind resource assessment. These models are based on a linearization of the Navier-Stokes equations, which was originally introduced in reference [2]. They were designed to be used reliably in neutral atmospheric conditions over terrain with sufficiently gentle slopes to ensure fully attached flow conditions.

$$\frac{\partial \tilde{u}_i}{\partial x_i} = 0, \text{ for } i = 1,..,3 \tag{1}$$

$$U_j \frac{\partial \tilde{u}_i}{\partial x_j} = -\frac{\partial}{\partial x_i}\frac{\tilde{p}}{\rho} + K_\mathrm{h}\frac{\partial}{\partial x_j}\left(\frac{\partial \tilde{u}_i}{\partial x_j}\right) + K_\mathrm{v}\frac{\partial^2 \tilde{u}_i}{\partial x_3^2}, \text{ for } i = 1,..,3 \text{ and } j = 1,2 \tag{2}$$

Here, $U_j\,(j=1,2)$ are the horizontal velocity components of the unperturbed flow, $\tilde{u}_i\,(i=1,\ldots,3)$ are the velocity perturbation components, and $\tilde{p}$ is the pressure perturbation. K_h and K_v are the effective kinematic viscosities in the horizontal and vertical directions.

Linear models perform reasonably well where the wind is not significantly affected by steep slopes, flow separation, thermally driven flows, low-level jets, and other dynamic and nonlinear ABL phenomena.

The Wind Atlas Analysis and Application Program (WAsP) [3] has been the most widely used amongst the linear models. WAsP procedures may be considered as a transfer function model linking the wind speeds at the reference with those at the predicted locations. Significant sources of error could be related to the terrain complexity, massive flow separation, wind direction changes, and varying atmospheric conditions. The latter include, among others, channeling effects, blocking effects, and thermally driven flows (e.g., diurnal sea breezes, downslope winds).

Due to their fast and robust performance, linear models are still used in the wind industry.