

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Wind energy generation systems –
Part 21-2: Measurement and assessment of electrical characteristics – Wind
power plants**

**Systèmes de génération d'énergie éolienne –
Partie 21-2: Mesurage et évaluation des caractéristiques électriques – Centrales
éoliennes**



THIS PUBLICATION IS COPYRIGHT PROTECTED
Copyright © 2023 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 Varembe
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 It also gives information on projects, replaced and withdrawn publications.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 request 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 preview. 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 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 21-2: Measurement and assessment of electrical characteristics – Wind
power plants**

**Systèmes de génération d'énergie éolienne –
Partie 21-2: Mesurage et évaluation des caractéristiques électriques – Centrales
éoliennes**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 27.180

ISBN 978-2-8322-6648-9

**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.....	9
INTRODUCTION.....	11
1 Scope.....	13
2 Normative references	14
3 Terms and definitions	15
4 Symbols and abbreviated terms.....	25
4.1 Symbols.....	25
4.2 Abbreviated terms.....	27
5 Power plant specifications	27
6 Overall test and documentation requirements	29
6.1 General.....	29
6.2 Test conditions, monitoring and reporting requirements	31
6.3 Test conditions in the case of external influences	33
6.4 Test and measurement equipment	33
6.4.1 General	33
6.4.2 Voltage, current and power calculations	33
6.4.3 Measurement equipment	33
6.4.4 Existing measurement equipment for power control tests.....	34
6.4.5 Optional measurements.....	34
6.5 Functional and performance test.....	34
6.6 Power plant controller	35
6.6.1 General	35
6.6.2 Definition and requirements	35
6.6.3 Measurement points	36
6.6.4 Measurement data.....	37
6.6.5 Test setup	37
6.6.6 Documentation	38
7 Measurement and test of electrical characteristics.....	39
7.1 General.....	39
7.2 Power quality aspects	39
7.2.1 General	39
7.2.2 Flicker during continuous operation	39
7.2.3 Rapid voltage changes due to switching operations	40
7.2.4 Harmonics	41
7.3 Steady state operation	43
7.3.1 General	43
7.3.2 Unbalance	43
7.4 Dynamic performance	44
7.4.1 Undervoltage and overvoltage ride-through (UVRT and OVRT) capability	44
7.4.2 Test setup and test conditions	44
7.4.3 Test and measurement procedure	44
7.4.4 Documentation	46
7.5 Disconnection from grid	47
7.5.1 Grid protection.....	47
7.5.2 Requirements of test devices.....	48

7.5.3	Grid protection test – PP level	48
7.5.4	Grid protection test – PGU level	49
7.5.5	RoCoF	49
8	Control performance	49
8.1	General	49
8.2	Performance test	49
8.2.1	General	49
8.2.2	Active power control tests	50
8.2.3	Controlled shutdown	52
8.2.4	Synthetic inertia response	54
8.2.5	Reactive power control	7
8.2.6	Reactive power capability	30
8.3	Functionality tests	63
8.3.1	General	63
8.3.2	Active power ramp rate limitation test	63
8.3.3	Priority of setpoints	65
8.3.4	Frequency control	67
8.3.5	Reactive power ramp rate limitation	72
8.3.6	Voltage control $Q(U)$ -characteristic	76
8.3.7	Power factor control	78
8.3.8	Communication error/fallback scenarios	81
9	Assessment of power quality of power plants (P ₂)	84
9.1	General	84
9.2	Voltage fluctuations	84
9.2.1	Voltage change	84
9.2.2	Flicker in continuous operation	85
9.2.3	Voltage change and flicker during switching operations	86
9.3	Current harmonics, interharmonics and higher frequency components	87
Annex A (informative)	Report template	89
A.1	Overview	89
A.2	Power plant specification and test conditions	89
A.3	Power plant controller	90
A.4	Power quality aspects	91
A.5	Steady state operation	120
A.6	Dynamic performance	121
A.7	Disconnection from grid (grid protection)	122
A.8	Performance test	122
A.8.1	General	122
A.8.2	Static error test	122
A.8.3	Dynamic response test	123
A.8.4	Controlled shutdown	123
A.8.5	Synthetic inertia response	124
A.8.6	Reactive power control	126
A.8.7	Reactive power capability	127
A.9	Functionality tests	128
A.9.1	Active power ramp rate limitation test	128
A.9.2	Priority of setpoints	129
A.9.3	Frequency control	130
A.9.4	Reactive power ramp rate limitation	131

A.9.5	Voltage control $Q(U)$ -characteristic	132
A.9.6	Power factor control.....	133
A.9.7	Communication error / fallback scenarios	135
Annex B (informative)	Harmonic evaluation.....	137
B.1	Harmonic estimation at the point of interest	137
B.2	Background harmonic distortion	137
B.3	Harmonic summation	138
B.4	Harmonic propagation studies.....	138
B.5	PP harmonic contribution evaluation	139
B.5.1	General	139
B.5.2	Incremental PP harmonic contribution based on simulations	139
B.5.3	PP electromagnetic compatibility analysis based on simulations	139
B.5.4	Harmonic measurements at the POC	140
Annex C (informative)	Validation procedure for PP	141
Annex D (informative)	Measurement accuracy	143
Bibliography	146
Figure 1	– Example of step response	19
Figure 2	– Example of a PP setup.....	29
Figure 3	– General structure of a PPC for reactive power control within a power plant	35
Figure 4	– General structure of a PPC for active power control within a power plant	36
Figure 5	– Illustration of the PPC as a black box with in- and outputs	36
Figure 6	– Illustration of the PPC with the internal system data.....	37
Figure 7	– Illustration of a complete test setup.....	38
Figure 8	– Example of time series for the active and reactive current measured (M) and simulated (S) active and reactive current [A].....	47
Figure 9	– Adjustment of active power reference value	51
Figure 10	– Example of active power response step	51
Figure 11	– Example of controlled shutdown.....	54
Figure 12	– Synthetic inertia – example response and definitions	56
Figure 13	– Test for static error.....	59
Figure 14	– Example of test of dynamic response	59
Figure 15	– Example of test of reactive power capability QP -chart	62
Figure 16	– Example of reactive power capability UP -chart corresponding to the QP -chart.....	62
Figure 17	– Example of available active power and active power in ramp rate limitation mode	64
Figure 18	– Example of active power setpoint prioritization test	66
Figure 19	– PPC measured frequency feedback is replaced by a simulated frequency	69
Figure 20	– Example of an active power control function $P = f(f)$, with the different measurement points and related steps of frequency	70
Figure 21	– Example of reactive power ramp rate limitation test.....	75
Figure 22	– Example of the $Q(U)$ characteristic with a 4 % slope.....	76
Figure 23	– Example of possible PP communication faults.....	81
Figure 24	– Example of graph for communication error test.....	83
Figure A.1 – Figure 25	– Voltage flicker P_{St} versus active power for normal operation	91

Figure A.2 – Voltage flicker P_{st} for background level	92
Figure A.3 – Time series of three-phase voltages as RMS of PP starting	92
Figure A.4 – Time series of three-phase currents as RMS of PP starting.....	92
Figure A.5 – Time series of active and reactive power of PP starting	92
Figure A.6 – Time series of three-phase voltages as RMS of PP stopping.....	93
Figure A.7 – Time series of three-phase currents as RMS of PP stopping	93
Figure A.8 – Time series of active and reactive power of PP stopping.....	93
Figure A.9 – Maximum of the 99 th percentiles of integer harmonic currents versus harmonic order	117
Figure A.10 – Maximum of the 99 th percentiles of interharmonic currents versus frequency.....	117
Figure A.11 – Maximum of the 99 th percentiles of higher frequency current components versus frequency.....	117
Figure A.12 – Maximum of the 95 th percentiles of integer harmonic currents versus harmonic order	117
Figure A.13 – Maximum of the 95 th percentiles of interharmonic current versus frequency.....	118
Figure A.14 – Maximum of the 95 th percentiles of higher frequency current components versus frequency.....	118
Figure A.15 – Maximum of the 99 th percentiles of integer harmonic voltages versus harmonic order	118
Figure A.16 – Maximum of the 99 th percentiles of interharmonic voltages versus frequency.....	118
Figure A.17 – Maximum of the 99 th percentiles of higher frequency voltage components versus frequency.....	119
Figure A.18 – Maximum of the 95 th percentiles of integer harmonic voltages versus harmonic order	119
Figure A.19 – Maximum of the 95 th percentiles of interharmonic voltages versus frequency.....	119
Figure A.20 – Maximum of the 95 th percentiles of higher frequency voltage components versus frequency.....	119
Figure A.21 – Current unbalance factor as a function of active power	120
Figure A.22 – Voltage unbalance factor as a function of active power	120
Figure A.23 – Time series: Instantaneous three-phase currents and voltages at the POC	121
Figure A.24 – Time series: Positive and negative sequence of the active and reactive current.....	121
Figure A.25 – Time series: Positive and negative sequence of the active and reactive power	121
Figure A.26 – Time series: Positive and negative sequence grid voltage at the POC	122
Figure A.27 – Time series of available active power, measured active power output and reference values	122
Figure A.28 – Time series of available active power, measured active power output and reference values	123
Figure A.29 – Time series of available active power, measured active power output and reference values	123

Figure A.30 – Time-series of available active power, measured active power and reference value of the grid frequency for (test 1 and test 2) $0,25 \times P_n < P < 0,5 \times P_n$	124
Figure A.31 – Time-series of available active power, measured active power and reference value of the grid frequency for (test 3 and test 4) $P > 0,8 \times P_n$	124
Figure A.32 – Time-series of available active power, measured active power and reference value of the grid frequency for (test 5 and test 6) $v > v_n$	124
Figure A.33 – Time-series of reactive power reference values and measured reactive power and grid voltage during the test of reactive power control	126
Figure A.34 – Time-series of reactive power reference values and measured reactive power, grid voltage during the test of reactive power control	126
Figure A.35 – Zoom of step response (for all three-step responses) in the time-series of reactive power reference values and measured reactive power, grid voltage during the test of reactive power control	127
Figure A.36 – Test of reactive power capability <i>QP</i> -chart	127
Figure A.37 – Reactive power capability <i>UP</i> -chart corresponding to the <i>QP</i> -chart	128
Figure A.38 – Time-series of available active power and active power in ramp rate limitation mode – Slow ramp rate	128
Figure A.39 – Time-series of available active power and active power in ramp rate limitation mode – Fast ramp rate	129
Figure A.40 – Time-series of active power setpoints, available power and active power	129
Figure A.41 – Time-series of active power setpoints, available power and active power	130
Figure A.42 – Time-series of simulated frequency	130
Figure A.43 – Time series of reactive power setpoint, reactive power	131
Figure A.44 – Time series of voltage – Reactive power, expected reactive power for a given slope	132
Figure A.45 – Time series of active power, reactive power, power factor and power factor reference	133
Figure A.46 – Time-series of active power setpoint, active power and available power and failure time point (case 1 to case 4)	135
Figure A.47 – Graph for communication error test (example)	136
Figure B.1 – Simplified representation for the PP connected to the external grid used for the estimation of incremental harmonic contribution at POC or any other point of interest	139
Figure B.2 – Simplified representation of the PP for harmonic propagation studies including the harmonic background and PGU's non-ideal harmonic voltage source	140
Table 1 – Overview of measurements and their requirements	30
Table 2 – Description and general requirements of the HIL test functional	38
Table 3 – List of recorded signals	45
Table 4 – List of electrical signals to be monitored for the evaluation of events	45
Table 5 – Maximum measurement uncertainties for the grid simulator	48
Table 6 – List of signals during test	50
Table 7 – Accuracy of the active power control values	52
Table 8 – Results from the active power dynamic response test	52
Table 9 – Example of list of signals during test	53
Table 10 – Results of the emergency shutdown test	54
Table 11 – List of signals during test	55

Table 12 – Synthetic inertia settings	57
Table 13 – Synthetic inertia test results	57
Table 14 – List of signals during test.....	58
Table 15 – Test for static error.....	60
Table 16 – Test for dynamic response	60
Table 17 – List of signals during test.....	61
Table 18 – Example of reactive power capability QP -chart	63
Table 19 – List of signals during test.....	63
Table 20 – Active power ramp rate calculation	65
Table 21 – List of signals during test.....	66
Table 22 – Test results priority of setpoints.....	67
Table 23 – List of signals during test.....	68
Table 24 – Example of test sequence for the frequency dependent active power function.....	72
Table 25 – List of signals during test.....	73
Table 26 – Test procedure reactive power ramp rate limitation test	74
Table 27 – Reactive power ramp rate calculation	75
Table 28 – List of signals during test.....	77
Table 29 – Voltage control $Q(U)$ – slope test.....	78
Table 30 – List of signals during test.....	79
Table 31 – Example of power factor control test.....	80
Table 32 – List of signals during test.....	82
Table 33 – Example of communication error test – Failure on external interface	83
Table 34 – Example of failure of PPC or communication between PPC and PGUs	83
Table 35 – Example of failure of grid data measurement.....	84
Table 36 – Specification of exponents according to IEC TR 61000-3-6.....	88
Table A.1 – General and nominal data.....	89
Table A.2 – General power plant capabilities and control functions	90
Table A.3 – General test and report information.....	90
Table A.4 – General test conditions and grid data.....	90
Table A.5 – General test conditions and test setup	91
Table A.6 – Flicker values.....	91
Table A.7 – Rapid voltage changes due to switching operations	92
Table A.8 – General test information.....	93
Table A.9 – 99 th percentile of 10 min harmonic magnitudes per week.....	94
Table A.10 – 99 th percentile of 10 min harmonic magnitudes per week.....	95
Table A.11 – 99 th percentile of 10 min harmonic magnitudes per week.....	97
Table A.12 – 95 th percentile of 10 min harmonic magnitudes per week.....	98
Table A.13 – 95 th percentile of 10 min harmonic magnitudes per week.....	99
Table A.14 – 95 th percentile of 10 min harmonic magnitudes per week.....	101
Table A.15 – 99 th percentile of 10 min harmonic magnitudes per week.....	102
Table A.16 – 99 th percentile of 10 min harmonic magnitudes per week.....	103

Table A.17 – 99 th percentile of 10 min harmonic magnitudes per week.....	105
Table A.18 – 95 th percentile of 10 min harmonic magnitudes per week.....	106
Table A.19 – 95 th percentile of 10 min harmonic magnitudes per week.....	107
Table A.20 – 95 th percentile of 10 min harmonic magnitudes per week.....	108
Table A.21 – 99 th percentile of 3 s harmonic magnitudes per week	109
Table A.22 – 99 th percentile of 3 s harmonic magnitudes per week	111
Table A.23 – 99 th percentile of 3 s harmonic magnitudes per week	112
Table A.24 – 99 th percentile of 3 s harmonic magnitudes per week	113
Table A.25 – 99 th percentile of 3 s harmonic magnitudes per week	114
Table A.26 – 99 th percentile of 3 s harmonic magnitudes per week	116
Table A.27 – Unbalance.....	120
Table A.28 – General fault information of undervoltage and overvoltage ride through (UVRT and OVRT) events/record ^a	121
Table A.29 – Accuracy of the active power control values	122
Table A.30 – Accuracy of the active power control values	123
Table A.31 – Results of the emergency shutdown test	123
Table A.32 – Synthetic inertia test results	125
Table A.33 – Test for static error.....	126
Table A.34 – Test for dynamic response	127
Table A.35 – <i>PQ</i> -diagram.....	128
Table A.36 – Active power ramp rate calculation – Slow ramp rate	129
Table A.37 – Active power ramp rate calculation – Fast ramp rate	129
Table A.38 – Test results priority of setpoint	130
Table A.39 – Frequency dependent active power function results	131
Table A.40 – Reactive power ramp rate calculation.....	132
Table A.41 – Voltage control $V(U)$ – slope test.....	133
Table A.42 – Power factor control test	134
Table A.43 – Communication error test – Failure on external interface (example)	135
Table A.44 – Failure of PPC or communication between PPC and PGUs (example).....	135
Table A.45 – Failure of grid data measurement (example)	135
Table A.46 – Communication error test – Failure on external interface (example)	136
Table A.47 – Failure of PPC or communication between PPC and PGUs (example).....	136
Table A.48 – Failure of grid data measurement (example)	136
Table C.1 – Recommended assessment methods for the validation of the electrical capabilities of the PP	141
Table D.1 – Voltage transducer (VT) in MV, HV and EHV.....	143
Table D.2 – Current transducer (CT) in MV, HV und EHV.....	144

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –**Part 21-2: Measurement and assessment of electrical characteristics –
Wind power plants**

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.

IEC 61400-21-2 has been prepared by technical committee 88: Wind energy generation systems. It is an International Standard.

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

Draft	Report on voting
88/933/FDIS	88/943/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.

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.

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 document 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

This part of IEC 61400 defines a uniform method that will ensure the measurement, testing and assessment of the electrical characteristics of grid connected wind power plants. These characteristics include: power quality aspects, control characteristics such as power control, reactive power control, voltage control, frequency control, fault ride-through behaviour, as well as grid protection testing.

The measurements and assessment refer to the point of connection (POC) of the power plant. The procedure describes standardized methods, which will allow the developer as well as system operators (e.g. transmission system operators (TSOs) and distribution system operators (DSOs)) to analyze the fulfilment of the grid connection rules with respect to the above-mentioned characteristics.

This document includes the following aspects:

- definition and specification of the quantities to be determined for characterizing the electrical characteristics of grid connected power plants;
- measurement and test procedures for quantifying the electrical characteristics of a power plant;
- measurement and test procedures of the power plant controller;
- procedures and methods for the estimation of electrical capabilities, using results from each of the wind turbine measurements to assess compliance with electrical connection requirements on power plant level;
- test and measurement procedures that can be used as a reference, for example commissioning tests for existing or newly connected power plants;
- procedures for measurement and fault recording for the validation and verification of wind power plant simulation models as described in IEC 61400-27-1 and IEC 61400-27-2.

These measurement procedures are valid for power plants, including the power plant controller (PPC) and other connected equipment necessary for the operation of the power plant. The measurement procedures are valid for any size of power plant connected to the POC with a single interface.

The results of the measurements and assessment of the power plant's electrical characteristics can be used as input for the verification of the electrical simulation models for wind power plants as described in IEC 61400-27-2.

Any aspects described in this document can be tested and reported individually, and it is not mandatory to perform all of the described tests and measurements.

The validation of control functions on the power plant is a combination of the performance of the individual power generation units (PGUs), any additional plant components, the communication system and the PPC.

The control performance of the power plant can be proved by a combination of performance tests on site and functionality tests carried out on a hardware-in-the-loop (HIL) setup.

The validation tests for the control performance are therefore divided into two parts:

- 1) performance tests
- 2) functionality tests

Functionality tests can be carried out either on a specific test setup (HIL test) or on site.

Performance tests, which are site-dependent, are done at each specific site under the specific site conditions and provide together with the functionality tests the complete control performance of the power plant.

Additional tests and measurements may be carried out and reported on for more detailed assessment of simulation models and compliance with specific grid code requirements.

As the described tests can be used for the validation of other renewable power plants, this document uses the following generic abbreviations:

- PGU: power generation unit as an abbreviated term for a wind turbine
- PP: power plant as the abbreviated term for wind power plant

WIND ENERGY GENERATION SYSTEMS –

Part 21-2: Measurement and assessment of electrical characteristics – Wind power plants

1 Scope

This part of IEC 61400 defines and specifies the quantities that are determined to characterize the electrical characteristics of grid-connected power plants (PPs).

This document defines the measurement and test procedures for quantifying the electrical characteristics as basis for the verification of compliance of PPs, including:

- power quality aspects,
- steady state operation,
- dynamic response (undervoltage and overvoltage fault ride-through),
- disconnection from grid (grid protection),
- control performance.

This document defines a uniform functionality test and measurement procedure for the power plant controller (PPC), as a basis for the unit test of the power plant controller.

This document defines the procedures for assessing compliance with electrical connection requirements, including the aggregation methods for power quality aspects such as voltage variations, flicker, harmonics and interharmonics.

This document defines the procedures for measurement and fault recording, for example for the verification of power plant electrical simulation models in relation to undervoltage and overvoltage ride-through events.

These measurement procedures are valid for power plants, including the power plant controller and other connected equipment, necessary for the operation of the power plant. The measurement procedures are valid for any size of power plant connected to the point of connection (POC) at one connection point.

The procedures for assessing and verifying the compliance with grid connection requirements are valid for power plants in power systems with fixed frequency and a sufficient short-circuit power.

Out of the scope of this document are:

- evaluation of several power plants, i.e. the control by a cluster management of several power plants (PPs) or evaluation where the power plant is connected to several connection points;
- compliance test and performance requirements, including pass or fail criteria;
- specific component test and validation of the PP equipment (switchgear, cables, transformers, etc.), which are covered by other IEC standards;
- wind power plant model validation, as defined in IEC 61400-27-2;
- load flow calculation methods and load flow study guidelines;
- test and measurement of the communication interface and system of the PP as defined in the IEC 61400-25 series.