IEC 61400-27-2

Edition 1.0 2020-07

INTERNATIONAL STANDARD

colour inside

Wind energy generation systems –
Part 27-2: Electrical simulation models – Model validation

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.180

ISBN 978-2-8322-8506-0

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

® Registered trademark of the International Electrotechnical Commission

CONTENTS

FOREWORD 6
INTRODUCTION 8
1 Scope 10
2 Normative references 10
3 Terms, definitions, abbreviations and subscripts 11
3.1 Terms and definitions 11
3.2 Abbreviations and subscripts 15
3.2.1 Abbreviations 15
3.2.2 Subscripts 15
4 Symbols and units 15
4.1 General 15
4.2 Symbols (units) 16
5 Functional specifications and requirements to validation procedures 18
5.1 General 18
5.2 General specifications 18
5.3 Wind turbine model validation 20
5.4 Wind power plant model validation 20
6 General methodologies for model validation 20
6.1 General 20
6.2 Test results 20
6.3 Simulations 21
6.4 Signal processing 21
6.4.1 General 21
6.4.2 Time series processing 21
6.4.3 Windows error statistics 23
6.4.4 FRT windows specification 24
6.4.5 Step response characteristics 25
7 Validation of wind turbine models 27
7.1 General 27
7.2 Fault ride through capability 27
7.2.1 General 27
7.2.2 Test requirements 28
7.2.3 Simulation requirements 29
7.2.4 Validation results 29
7.3 Active power control 29
7.3.1 General 29
7.3.2 Test requirements 29
7.3.3 Simulation requirements 30
7.3.4 Validation results 30
7.4 Frequency control 30
7.4.1 General 30
7.4.2 Test requirements 30
7.4.3 Simulation requirements 31
7.4.4 Validation results 31
7.5 Synthetic inertia control 31
7.5.1 General 31

7.5.2 Test requirements 31
7.5.3 Simulation requirements 32
7.5.4 Validation results 32
7.6 Reactive power reference control 32
7.6.1 General 32
7.6.2 Test requirements 32
7.6.3 Simulation requirements 33
7.6.4 Validation results 33
7.7 Reactive power – voltage reference control 33
7.7.1 General 33
7.7.2 Test requirements 33
7.7.3 Simulation requirements 33
7.7.4 Validation results 34
7.8 Grid protection 34
7.8.1 General 34
7.8.2 Test requirements 34
7.8.3 Simulation requirements 34
7.8.4 Validation results 35
8 Validation of wind power plant models 35
8.1 General 35
8.2 Active power control 35
8.2.1 General 35
8.2.2 Test requirements 36
8.2.3 Simulation requirements 36
8.2.4 Validation results 36
8.3 Reactive power reference control 36
8.3.1 General 36
8.3.2 Test requirements 37
8.3.3 Simulation requirements 37
8.3.4 Validation results 37
8.4 Reactive power – voltage reference control 37
8.4.1 General 37
8.4.2 Test requirements 38
8.4.3 Simulation requirements 38
8.4.4 Validation results 38
Annex A (informative) Validation documentation for wind turbine model 39
A.1 General 39
A.2 Simulation model and validation setup information 39
A.3 Template for validation results 39
A.3.1 General 39
A.3.2 Fault ride through capability 40
A.3.3 Active power control 42
A.3.4 Frequency control 42
A.3.5 Synthetic inertia control 43
A.3.6 Reactive power reference control 43
A.3.7 Reactive power – voltage reference control 44
A.3.8 Grid protection 45
Annex B (informative) Validation documentation for wind power plant model 46
B.1 General 46

B.2 Simulation model and validation setup information 46
B.3 Template for validation results 46
B.3.1 General 46
B.3.2 Active power control 47
B.3.3 Reactive power reference control 47
B.3.4 Reactive power – voltage reference control 48
Annex C (informative) Reference grid for model-to-model validation 49
Annex D (informative) Model validation uncertainty 50
D.1 General 50
D.2 Simulation uncertainties 50
D.3 Measurement uncertainties 50
D.4 Impact of model validation uncertainties 51
Annex E (normative) Digital 2nd order critically damped low pass filter 52
Annex F (informative) Additional performance based model validation methodology for active power recovery in voltage dips 53
F.1 General 53
F.2 Active power recovery criterion 53
F.3 Active power oscillation criterion 53
Annex G (informative) Generic software interface for use of models in different software environments 55
G.1 Description of the approach 55
G.2 Description of the software interface 56
G.2.1 Description of data structures 56
G.2.2 Functions for communication through the ESE-interface 58
G.2.3 Inputs, outputs, parameters 59
Bibliography 60

Figure 1 – Classification of power system stability according to IEEE/CIGRE Joint Task Force on Stability Terms and Definitions [1] 8
Figure 2 – Signal processing structure with play-back simulation approach applied 22
Figure 3 – Signal processing structure with full-system simulation approach applied 22
Figure 4 – Voltage dip windows [12] 24
Figure 5 – Step response characteristics 26
Figure 6 – Measured and simulated settling time with inexpedient choice of tolerance band 27
Figure A.1 – Time series of measured and simulated positive sequence voltage 40
Figure A.2 – Time series of measured and simulated positive sequence active current 40
Figure A.3 – Time series of measured and simulated positive sequence reactive current 40
Figure A.4 – Time series of calculated absolute error of positive sequence active and reactive current 40
Figure A.5 – Time series of measured and simulated negative sequence voltage 41
Figure A.6 – Time series of measured and simulated negative sequence active current 41
Figure A.7 – Time series of measured and simulated negative sequence reactive current 41
Figure A.8 – Time series of calculated absolute error of negative sequence active and reactive current 41

Figure A.9 – Time series of active power reference, available active power, measured active power and simulated active power 42
Figure A.10 – Time series of frequency reference value and measured input to WT controller 43
Figure A.11 – Time series of available active power, measured active power and simulated active power 43
Figure A.12 – Time series of frequency reference value and measured input to WT controller 43
Figure A.13 – Time series of available active power, measured active power and simulated active power 43
Figure A.14 – Time series of reactive power reference, measured reactive power and simulated reactive power 44
Figure A.15 – Time series of measured active power and simulated active power 44
Figure A.16 – Time series of measured and simulated reactive power 44
Figure B.1 – Time series of active power reference, available active power, measured active power and simulated active power 47
Figure B.2 – Time series of reactive power reference, measured reactive power and simulated reactive power 47
Figure B.3 – Time series of measured active power and simulated active power 47
Figure B.4 – Time series of measured and simulated reactive power 48
Figure C.1 – Layout of reference grid 49
Figure F.1 – Voltage dip active power performance validation parameters 54
Figure G.1 – Sequence of simulation on use of ESE-interface 59

Table 1 – Windows applied for error calculations 25
Table A.1 – Required information about simulation model and validation setup 39
Table A.2 – Additional information required if full-system method is applied 39
Table A.3 – Positive sequence validation summary for each voltage dip and voltage swell validation case 41
Table A.4 – Negative sequence validation summary for each voltage dip and voltage swell validation case 42
Table A.5 – Validation summary for active power control 42
Table A.6 – Validation summary for reactive power control 44
Table A.7 – Validation summary for grid protection 45
Table B.1 – Required information about simulation model and validation setup 46
Table B.2 – Additional information required if full-system method is applied 46
Table B.3 – Validation summary for active power control 47
Table B.4 – Validation summary for reactive power control 47
Table C.1 – Line data for the WECC test system in per-unit 49
Table C.2 – Transformer data for the WECC test system 49

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

WIND ENERGY GENERATION SYSTEMS –

Part 27-2: Electrical simulation models – Model validation

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 shall 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 61400-27-2 has been prepared by IEC technical committee 88: Wind energy generation systems.

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

FDIS	Report on voting
88/763/FDIS	88/772/RVD

Full information on the voting for the approval of this International 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, published 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 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

IEC 61400-27-2 specifies model validation procedures for electrical simulation models of wind turbines and wind power plants.

The increasing penetration of wind energy in power systems implies that Transmission System Operators (TSOs) and Distribution System Operators (DSOs) need to use dynamic models of wind power generation for power system stability studies.

The purpose of this International Standard is to specify validation procedures for dynamic models, which can be applied in power system stability studies. The IEEE/CIGRE Joint Task Force on Stability Terms and Definitions [1][1] has classified power system stability in categories according to Figure 1.

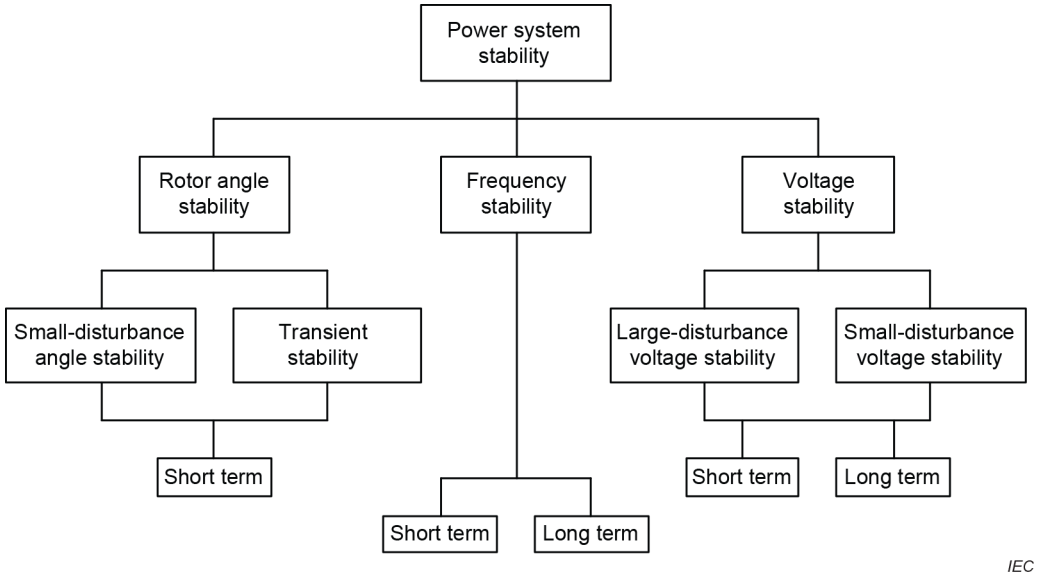

Figure 1 – Classification of power system stability according to IEEE/CIGRE Joint Task Force on Stability Terms and Definitions [1]

Referring to these categories, the models to be validated have been developed to represent wind power generation in studies of large-disturbance short term stability phenomena, i.e. short term voltage stability, short term frequency stability and short term transient stability studies referring to the definitions of IEEE/CIGRE Joint Task Force on Stability Terms and Definitions in Figure 1. Thus, the models are applicable for dynamic simulations of power system events such as short-circuits (low voltage ride through), loss of generation or loads, and system separation of one synchronous area into more synchronous areas.

The validation procedure specified in this document assesses the accuracy of the fundamental frequency response of wind power plant models and wind turbine models. This includes validation of the generic positive sequence models specified in IEC 61400-27-1 and validation of positive sequence as well as negative sequence response of more detailed models developed by the wind turbine manufacturers.

---

1 Figures in square brackets refer to the Bibliography.

The validation procedure has the following limitations:

– The validation procedure does not specify any requirements to model accuracy. It only specifies measures to quantify the accuracy of the model[2],[3].

– The validation procedure does not specify test and measurement procedures, as it is intended to be based on tests specified in IEC 61400-21-1 and IEC 61400-21-2[4].

– The validation procedure is not intended to justify compliance to any grid code requirement, power quality requirements or national legislation.

– The validation procedure does not include validation of steady state capabilities e.g. of reactive power, but focuses on validation of the dynamic performance of the models.

– The validation procedure does not cover long term stability analysis.

– The validation procedure does not cover sub-synchronous interaction phenomena.

– The validation procedure does not cover investigation of the fluctuations originating from wind speed variability in time and space.

– The validation procedure does not cover phenomena such as harmonics, flicker or any other EMC emissions included in the IEC 61000 series.

– The validation procedure does not cover eigenvalue calculations for small signal stability analysis.

– This validation procedure does not address the specifics of short-circuit calculations.

– The validation procedure is limited by the functional specifications in Clause 5.

The following stakeholders are potential users of the validation procedures specified in this document:

– TSOs and DSOs need procedures to validate the accuracy of the models which they use in power system stability studies;

– wind plant owners are typically responsible to provide validation of their wind power plant models to TSO and/or DSO prior to plant commissioning;

– wind turbine manufacturers will typically provide validation of the wind turbine models to the owner.

– developers of modern software for power system simulation tools may use the standard to implement validation procedures as part of the software library;

– certification bodies in case of independent model validation;

– education and research communities, who can also benefit from standard model validation procedures.

---

2 Specification of requirements to model accuracy is the responsibility of TSOs e.g. in grid codes. The scope of IEC 61400-27-2 is to provide a standard for how to measure accuracy and this way remove indefiniteness.

3 Clause 7 specifies a large number of measures for model accuracy. The importance of the individual measure depends on the type of grid and type of stability study. Annex D describes limits to the possible accuracy of the models.

4 Under consideration.

WIND ENERGY GENERATION SYSTEMS –

Part 27-2: Electrical simulation models – Model validation

1 Scope

This part of IEC 61400 specifies procedures for validation of electrical simulation models for wind turbines and wind power plants, intended to be used in power system and grid stability analyses. The validation procedures are based on the tests specified in IEC 61400-21 (all parts). The validation procedures are applicable to the generic models specified in IEC 61400-27-1 and to other fundamental frequency wind power plant models and wind turbine models.

The validation procedures for wind turbine models focus on fault ride through capability and control performance. The fault ride through capability includes response to balanced and unbalanced voltage dips as well as voltage swells. The control performance includes active power control, frequency control, synthetic inertia control and reactive power control. The validation procedures for wind turbine models refer to the tests specified in IEC 61400-21-1. The validation procedures for wind turbine models refer to the wind turbine terminals.

The validation procedures for wind power plant models is not specified in detail because IEC 61400-21-2 which has the scope to specify tests of wind power plants is at an early stage. The validation procedures for wind power plant models refer to the point of connection of the wind power plant.

The validation procedures specified in IEC 61400-27-2 are based on comparisons between measurements and simulations, but they are independent of the choice of software simulation tool.

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.

IEC 60050-415:1999, *International Electrotechnical Vocabulary (IEV) – Part 415: Wind turbine generator systems* (available at www.electropedia.org)

IEC 61400-21-1:2019, *Wind energy generation systems – Part 21-1: Measurement and assessment of electrical characteristics – Wind turbines*

IEC 61400-27-1, *Wind energy generation systems – Part 27-1: Electrical simulation models – Generic models*