INTERNATIONAL STANDARD

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.
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
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5.2</td>
<td>Test requirements</td>
<td>31</td>
</tr>
<tr>
<td>7.5.3</td>
<td>Simulation requirements</td>
<td>32</td>
</tr>
<tr>
<td>7.5.4</td>
<td>Validation results</td>
<td>32</td>
</tr>
<tr>
<td>7.6</td>
<td>Reactive power reference control</td>
<td>32</td>
</tr>
<tr>
<td>7.6.1</td>
<td>General</td>
<td>32</td>
</tr>
<tr>
<td>7.6.2</td>
<td>Test requirements</td>
<td>32</td>
</tr>
<tr>
<td>7.6.3</td>
<td>Simulation requirements</td>
<td>33</td>
</tr>
<tr>
<td>7.6.4</td>
<td>Validation results</td>
<td>33</td>
</tr>
<tr>
<td>7.7</td>
<td>Reactive power – voltage reference control</td>
<td>33</td>
</tr>
<tr>
<td>7.7.1</td>
<td>General</td>
<td>33</td>
</tr>
<tr>
<td>7.7.2</td>
<td>Test requirements</td>
<td>33</td>
</tr>
<tr>
<td>7.7.3</td>
<td>Simulation requirements</td>
<td>33</td>
</tr>
<tr>
<td>7.7.4</td>
<td>Validation results</td>
<td>34</td>
</tr>
<tr>
<td>7.8</td>
<td>Grid protection</td>
<td>34</td>
</tr>
<tr>
<td>7.8.1</td>
<td>General</td>
<td>34</td>
</tr>
<tr>
<td>7.8.2</td>
<td>Test requirements</td>
<td>34</td>
</tr>
<tr>
<td>7.8.3</td>
<td>Simulation requirements</td>
<td>34</td>
</tr>
<tr>
<td>7.8.4</td>
<td>Validation results</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>Validation of wind power plant models</td>
<td>35</td>
</tr>
<tr>
<td>8.1</td>
<td>General</td>
<td>35</td>
</tr>
<tr>
<td>8.2</td>
<td>Active power control</td>
<td>35</td>
</tr>
<tr>
<td>8.2.1</td>
<td>General</td>
<td>35</td>
</tr>
<tr>
<td>8.2.2</td>
<td>Test requirements</td>
<td>36</td>
</tr>
<tr>
<td>8.2.3</td>
<td>Simulation requirements</td>
<td>36</td>
</tr>
<tr>
<td>8.2.4</td>
<td>Validation results</td>
<td>36</td>
</tr>
<tr>
<td>8.3</td>
<td>Reactive power reference control</td>
<td>36</td>
</tr>
<tr>
<td>8.3.1</td>
<td>General</td>
<td>36</td>
</tr>
<tr>
<td>8.3.2</td>
<td>Test requirements</td>
<td>37</td>
</tr>
<tr>
<td>8.3.3</td>
<td>Simulation requirements</td>
<td>37</td>
</tr>
<tr>
<td>8.3.4</td>
<td>Validation results</td>
<td>37</td>
</tr>
<tr>
<td>8.4</td>
<td>Reactive power – voltage reference control</td>
<td>37</td>
</tr>
<tr>
<td>8.4.1</td>
<td>General</td>
<td>37</td>
</tr>
<tr>
<td>8.4.2</td>
<td>Test requirements</td>
<td>38</td>
</tr>
<tr>
<td>8.4.3</td>
<td>Simulation requirements</td>
<td>38</td>
</tr>
<tr>
<td>8.4.4</td>
<td>Validation results</td>
<td>38</td>
</tr>
</tbody>
</table>

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
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:

<table>
<thead>
<tr>
<th>FDIS</th>
<th>Report on voting</th>
</tr>
</thead>
<tbody>
<tr>
<td>88/763/FDIS</td>
<td>88/772/RVD</td>
</tr>
</tbody>
</table>

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