



BSI Standards Publication

Wind energy generation systems

Part 27-1: Electrical simulation models — Generic models

National foreword

This British Standard is the UK implementation of EN IEC 61400-27-1:2020. It is identical to IEC 61400-27-1:2020. It supersedes BS EN 61400-27-1:2015, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PEL/88, Wind turbines.

A list of organizations represented on this committee can be obtained on request to its committee manager.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2020
Published by BSI Standards Limited 2020

ISBN 978 0 580 96167 0

ICS 27.180

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 September 2020.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

English Version

**Wind energy generation systems - Part 27-1: Electrical
simulation models - Generic models
(IEC 61400-27-1:2020)**

Systèmes de génération d'énergie éolienne - Partie 27-1:
Modèles de simulation électrique - Modèles génériques
(IEC 61400-27-1:2020)

Windenergieanlagen - Teil 27-1: Elektrische
Simulationsmodelle - Generische Modelle
(IEC 61400-27-1:2020)

This European Standard was approved by CENELEC on 2020-09-03. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.



European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

The text of document 88/762/FDIS, future edition 2 of IEC 61400-27-1, prepared by IEC/TC 88 "Wind energy generation systems" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 61400-27-1:2020.

The following dates are fixed:

- latest date by which the document has to be implemented at national (dop) 2021-06-03 level by publication of an identical national standard or by endorsement
- latest date by which the national standards conflicting with the (dow) 2023-09-03 document have to be withdrawn

This document supersedes EN 61400-27-1:2015 and all of its amendments and corrigenda (if any).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 61400-27-1:2020 was approved by CENELEC as a European Standard without any modification.

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60050-415	1999	International Electrotechnical Vocabulary -- Part 415: Wind turbine generator systems		-
IEC 61970-301	-	Energy management system application program interface (EMS-API) - Part 301: Common information model (CIM) base	EN IEC 61970-301	-
IEC 61970-302	-	Energy management system application program interface (EMS-API) - Part 302: Common information model (CIM) dynamics	EN IEC 61970-302	-

This page deliberately left blank

CONTENTS

FOREWORD.....	8
INTRODUCTION.....	10
1 Scope.....	12
2 Normative references	12
3 Terms, definitions, abbreviations and subscripts.....	12
3.1 Terms and definitions.....	12
3.2 Abbreviations and subscripts	16
3.2.1 Abbreviations.....	16
3.2.2 Subscripts	18
4 Symbols and units	19
4.1 General.....	19
4.2 Symbols (units).....	19
5 Functional specification of models	23
5.1 General specifications.....	23
5.2 Wind turbine models	24
5.3 Wind power plant models	25
6 Formal specification of modular structures of models.....	25
6.1 General.....	25
6.2 Wind turbine models	26
6.2.1 General	26
6.2.2 Type 1	26
6.2.3 Type 2	28
6.2.4 Type 3	30
6.2.5 Type 4	32
6.3 Auxiliary equipment models	37
6.3.1 STATCOM	37
6.3.2 Other auxiliary equipment.....	38
6.4 Wind power plant models	38
6.4.1 General	38
6.4.2 Wind power plant control and communication	39
6.4.3 Basic wind power plant.....	40
6.4.4 Wind power plant with reactive power compensation	41
7 Formal specification of modules	42
7.1 General.....	42
7.2 Aerodynamic modules.....	43
7.2.1 Constant aerodynamic torque module.....	43
7.2.2 One-dimensional aerodynamic module	44
7.2.3 Two-dimensional aerodynamic module	44
7.3 Mechanical modules	46
7.3.1 Two mass module.....	46
7.3.2 Other mechanical modules	46
7.4 Generator and converter system modules	46
7.4.1 Asynchronous generator module.....	46
7.4.2 Type 3A generator system module.....	47
7.4.3 Type 3B generator system module.....	48
7.4.4 Type 4 generator system module.....	49

7.4.5	Reference frame rotation module	50
7.5	Electrical systems modules	51
7.5.1	Electrical systems gamma module	51
7.5.2	Other electrical systems modules	52
7.6	Pitch control modules.....	52
7.6.1	Pitch control power module.....	52
7.6.2	Pitch angle control module.....	53
7.7	Generator and converter control modules	54
7.7.1	Rotor resistance control module	54
7.7.2	P control module type 3	55
7.7.3	P control module type 4A.....	58
7.7.4	P control module type 4B.....	59
7.7.5	Q control module	60
7.7.6	Current limitation module.....	63
7.7.7	Constant Q limitation module.....	64
7.7.8	QP and QU limitation module.....	65
7.8	Grid interfacing modules	66
7.8.1	Grid protection module	66
7.8.2	Grid measurement module.....	67
7.9	Wind power plant control modules.....	68
7.9.1	WP P control module	68
7.9.2	WP Q control module.....	69
7.10	Communication modules	71
7.10.1	General	71
7.10.2	Communication delay module	71
7.10.3	Linear communication module	71
7.11	Electrical components modules.....	72
7.11.1	Line module.....	72
7.11.2	Transformer module	72
7.11.3	Other electrical components modules	72
Annex A (informative)	Estimation of parameters for single branch power collection system model.....	73
A.1	General.....	73
A.2	Description of method	73
A.2.1	General	73
A.2.2	Lines aggregation	73
A.2.3	Wind turbine transformers aggregation	74
A.3	Numerical example	75
Annex B (informative)	Two-dimensional aerodynamic model	78
B.1	Objective	78
B.2	Wind speed input model.....	78
B.3	Parameters for power input module.....	80
Annex C (informative)	Implementation of generator systems modules with external impedance	81
Annex D (normative)	Block symbol library	84
D.1	General.....	84
D.2	Switch.....	84
D.3	Time step delay	84
D.4	Stand-alone ramp rate limiter	84

D.5	First order filter	85
D.6	Lookup table	86
D.7	Comparator	86
D.8	Timer	87
D.9	Anti windup integrator	88
D.10	Integrator with reset	88
D.11	First order filter with limitation detection	89
D.12	Rising edge detection	89
D.13	Falling edge detection	90
D.14	Delay flag	90
D.15	Variable delay flag	91
D.16	Dead band	92
D.17	Circuit breaker	92
	Bibliography	93

Figure 1 – Classification of power system stability according to IEEE/CIGRE Joint Task Force on Stability Terms and Definitions [9]	10
Figure 2 – Generic structure of WT models	26
Figure 3 – Modular structure of the type 1A WT model	27
Figure 4 – Modular structure of the type 1B WT model	28
Figure 5 – Modular structure of the type 2 WT model	29
Figure 6 – Modular structure of the type 3A and type 3B WT models	30
Figure 7 – Modular generator control sub-structure of the type 3A and type 3B models	31
Figure 8 – Modular structure of the type 4A WT model	33
Figure 9 – Modular generator control sub-structure of the type 4A model	34
Figure 10 – Modular structure of the type 4B WT model	35
Figure 11 – Modular generator control sub-structure of the type 4B model	36
Figure 12 – Modular structure of STATCOM model	37
Figure 13 – Modular structure of the STATCOM control model	37
Figure 14 – General structure of WP model	38
Figure 15 – General modular structure of WP control and communication block	39
Figure 16 – Single line diagram for basic WP model	40
Figure 17 – Single line diagram for WP model with reactive power compensation	41
Figure 18 – Block diagram for constant aerodynamic torque module	44
Figure 19 – Block diagram for one-dimensional aerodynamic module	44
Figure 20 – Block diagram for two-dimensional aerodynamic module	45
Figure 21 – Block diagram for two mass module	46
Figure 22 – Block diagram for type 3A generator system module	47
Figure 23 – Block diagram for type 3B generator system module	49
Figure 24 – Block diagram for type 4 generator system module	50
Figure 25 – Block diagram for the reference frame rotation module	51
Figure 26 – Single line diagram for electrical systems gamma module	52
Figure 27 – Block diagram for pitch control power module	53
Figure 28 – Block diagram for pitch angle control module	54
Figure 29 – Block diagram for rotor resistance control module	

Figure 30 – Block diagram for type 3 P control module	57
Figure 31 – Block diagram for type 3 torque PI	58
Figure 32 – Block diagram for type 4A P control module	59
Figure 33 – Block diagram for type 4B P control module	60
Figure 34 – Block diagram for Q control module.....	62
Figure 35 – Block diagram for current limiter.....	64
Figure 36 – Block diagram for constant Q limitation module	65
Figure 37 – Block diagram for QP and QU limitation module	65
Figure 38 – Block diagram for grid protection system.....	67
Figure 39 – Block diagram for u-f measurement.....	68
Figure 40 – Block diagram for WP power/frequency control module	69
Figure 41 – Block diagram for WP reactive power/voltage control module	70
Figure 42 – Block diagram for communication delay module	71
Figure 43 – Block diagram for linear communication module for an example with N communication variables.....	72
Figure A.1 – WP power collection system example	75
Figure B.1 – Turbine aerodynamics model proposed by Fortmann (2014)	78
Figure C.1 – Type 3A generator system module with parallel reactance.....	81
Figure C.2 – Type 3B generator system module with parallel reactance.....	82
Figure C.3 – Type 4 generator system module with parallel reactance	83
Figure D.1 – Block symbol for switch with a) a variable flag input and b) a constant mode	84
Figure D.2 – Block symbol for single integration time step delay	84
Figure D.3 – Block symbol for stand-alone ramp rate limiter.....	85
Figure D.4 – Block diagram for implementation of the stand-alone ramp rate limiter.....	85
Figure D.5 – Block symbol for first order filter with absolute limits, rate limits and freeze flag	85
Figure D.6 – Block diagram for implementation of the first order filter with absolute limits, rate limits and freeze state.....	86
Figure D.7 – Block diagram for implementation of the freeze state without filter ($T = 0$).....	86
Figure D.8 – Block symbol for lookup table	86
Figure D.9 – Block symbols for comparators	87
Figure D.10 – Block symbol for timer	87
Figure D.11 – Function of timer.....	87
Figure D.12 – Block symbol for anti windup integrator.....	88
Figure D.13 – Block diagram for implementation of anti windup integrator.....	88
Figure D.14 – Block symbol for integrator with reset	88
Figure D.15 – Block symbol for first order filter with limitation detection	89
Figure D.16 – Block diagram for implementation of first order filter with limitation detection.....	89
Figure D.17 – Block symbol rising edge detection	89
Figure D.18 – Block diagram for rising edge detection	90
Figure D.19 – Block symbol falling edge detection	90
Figure D.20 – Block diagram for falling edge detection	90
Figure D.21 – Block symbol for delay flag	90

Figure D.22 – Block diagram for implementation of delay flag	91
Figure D.23 – Block symbol for delay flag	91
Figure D.24 – Block diagram for implementation of variable delay flag	92
Figure D.25 – Block symbol dead band	92
Figure D.26 – Block symbol for circuit breaker	92
Table 1 – Modules used in type 1A model	27
Table 2 – Modules used in type 1B model	28
Table 3 – Modules used in type 2 model	29
Table 4 – Modules used in type 3A model	31
Table 5 – Modules used in type 3B model	32
Table 6 – Modules used in type 4A model	34
Table 7 – Modules used in type 4B model	36
Table 8 – Modules used in STATCOM model	38
Table 9 – Modules used in WP control and communication model	40
Table 10 – Models and additional modules used in the basic WP model	41
Table 11 – Models and modules used in the WP model with reactive power compensation	42
Table 12 – Global model parameters	42
Table 13 – Initialisation variable used in module block diagrams	43
Table 14 – Parameter list for one-dimensional aerodynamic module	44
Table 15 – Parameter list for two-dimensional aerodynamic module	45
Table 16 – Parameter list for two-mass module	46
Table 17 – Parameter list for type 3A generator system module	47
Table 18 – Parameter list for type 3B generator system module	48
Table 19 – Parameter list for type 4 generator system module	50
Table 20 – Parameter list for reference frame rotation module	50
Table 21 – Parameter list for electrical systems gamma module	51
Table 22 – Parameter list for pitch control power module	52
Table 23 – Parameter list for pitch angle control module	53
Table 24 – Parameter list for rotor resistance control module	54
Table 25 – Parameter list for P control module type 3	55
Table 26 – Parameter list for P control module type 4A	58
Table 27 – Parameter list for P control module type 4B	59
Table 28 – General WT Q control modes M_{qG}	60
Table 29 – Reactive current injection for each FRT Q control modes M_{qFRT}	60
Table 30 – Parameter list for Q control module	61
Table 31 – Description of F_{FRT} flag values	63
Table 32 – Parameter list for current limiter module	63
Table 33 – Parameter list for constant Q limitation module	64
Table 34 – Parameter list for QP and QU limitation module	65
Table 35 – Parameter list for grid protection module	66
Table 36 – Parameter list for grid measurement module	

Table 37 – Parameter list for power/frequency control module	68
Table 38 – Parameter list for reactive power/voltage control module	69
Table 39 – Parameter list for communication delay module	71
Table 40 – Parameter list for linear communication module.....	71
Table A.1 – Lines parameters and aggregation calculations. The data is in per-units using WP base values.....	76
Table A.2 – Transformers parameters	76
Table A.3 – Estimated parameters for the single branch collection system model in 6.4.3	77
Table B.1 – Lookup table specifying the function $\partial p_{\omega}(v_0)$	79
Table B.2 – Parameter list for the wind speed input model.....	79

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –**Part 27-1: Electrical simulation models –
Generic models****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.

International Standard IEC 61400-27-1 has been prepared by IEC technical committee 88: Wind energy generation systems.

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

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

FDIS	Report on voting
88/762/FDIS	88/771/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.

This second edition cancels and replaces the first edition, published in 2015. This edition constitutes a technical revision and a restructure of the content into two parts. The new structure joins the models in part 27-1 and the validation procedures in part 27-2.

This edition includes the following significant technical changes with respect to the previous edition:

- a) "Wind turbines" changed to "Generic models" because wind power plant models are also included, and the model validation is moved to IEC 61400-27-2;
- b) specification of models for wind power plants including plant control, communication system model and aggregation procedure for power collection system in addition to the wind turbine models in the previous edition;
- c) moving validation procedures for wind turbine models from this edition to part 27-2;
- d) a more detailed modular structure separating wind turbine control into pitch control and generator system control and extracting grid measurement modules from the control modules. Figures are revised accordingly;
- e) inclusion of model for STATCOM;
- f) inclusion of electrical components modules.

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

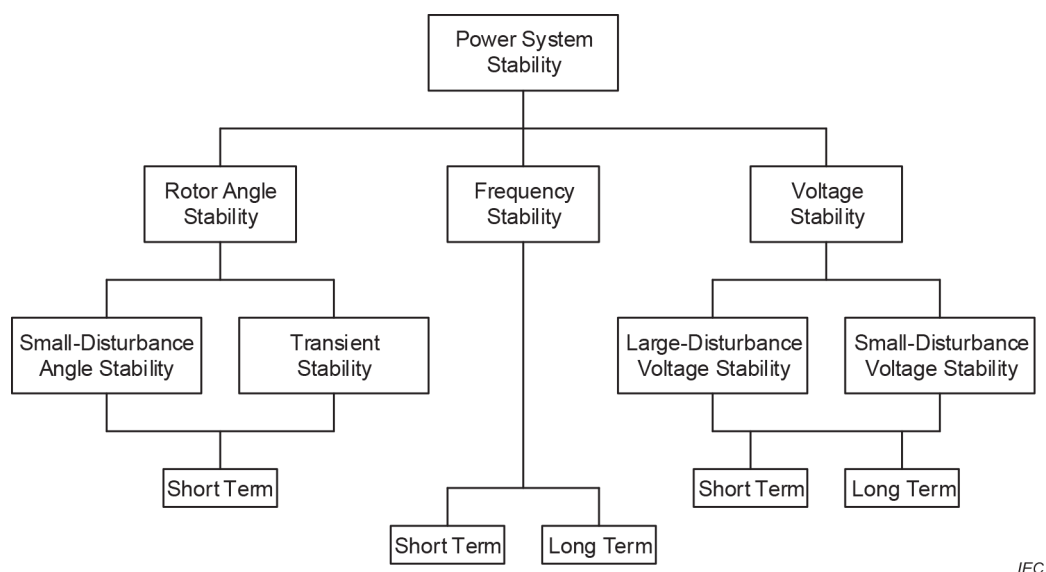
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

IEC 61400-27-1 specifies standard dynamic electrical simulation models for wind turbines and wind power plants. The specified wind turbine models can either be used in wind power plant models or to represent wind turbines without wind power plant relationships. Apart from the wind turbine models, the wind power plant model may include models for auxiliary equipment such as STATCOMs which are often used in 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 models developed by the wind turbine manufacturers reproduce the behaviour of their machines with a high level of detail. Such level of detail is not suitable for stability studies of large power systems with a huge number of wind power plants, firstly because the high level of detail increases the complexity and thus computer time dramatically, and secondly because the use of detailed manufacturer specific models requires a substantial amount of input data to represent the individual wind turbine types.

The purpose of this International Standard is to specify generic dynamic models, which can be applied in power system stability studies. The IEEE/CIGRE Joint Task Force on Stability Terms and Definitions [11]¹ has classified power system stability in categories according to Figure 1.



IEC

Figure 1 – Classification of power system stability according to IEEE/CIGRE Joint Task Force on Stability Terms and Definitions [11]

Referring to these categories, the models are 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 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 [12], and system separation of a synchronous system into more synchronous areas.

¹ The numbers in square brackets refer to the Bibliography.

The models shall be complete enough to represent the dynamic behavior of the wind power plant at the point of connection and of the wind turbine at the wind turbine terminals, but shall also be suitable for large-scale grid studies. Therefore, simplified models are specified to perform the typical response of known technologies.

The wind power plant models specified in this document are for fundamental frequency positive sequence response².

The models have the following limitations:

- The models are not intended for long term stability analysis.
- The models are not intended for investigation of sub-synchronous interaction phenomena.
- The models are not intended for investigation of the fluctuations originating from wind speed variability in time and space. This implies that the models do not include phenomena such as turbulence, tower shadow, wind shear and wakes.
- The models do not cover phenomena such as harmonics, flicker or any other EMC emissions included in the IEC 61000 series.
- The wind generation systems are highly non-linear and simplifications have been made in the development of the models. Thus, linearisation for eigenvalue analysis is not trivial nor necessarily appropriate based on these simplified models.
- This document does not address the specifics of short-circuit calculations.
- The models are not applicable to studies where wind turbines are islanded without synchronous generation.
- The models are not intended for studies of situations with short-circuit ratios less than 3. The short circuit limitation depends on wind turbine types, control modes and other settings. The WT manufacturer can specify a lower limit for the applicable short-circuit ratio provided that this application is validated according to part 27-2.
- The models are limited by the functional specifications in Clause 5.

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

- TSOs and DSOs are end users of the models, performing power system stability studies as part of the planning as well as the operation of the power systems.
- Wind plant owners are typically responsible to provide the wind power plant models to TSO and/or DSO prior to plant commissioning.
- Wind turbine manufacturers will typically provide the wind turbine models to the owner.
- Developers of modern software for power system simulation tools will use the standard to implement standard wind power models as part of the software library.
- Certification bodies in case of independent wind turbine model validation.
- Consultants who use models on behalf of TSOs, DSOs and/or wind plant developers.
- Education and research communities, who can also benefit from the generic models, as the manufacturer specific models are typically confidential.

² This document is dealing with balanced as well as unbalanced faults, but for unbalanced faults, only the positive sequence components are specified.

WIND ENERGY GENERATION SYSTEMS –

Part 27-1: Electrical simulation models – Generic models

1 Scope

This part of IEC 61400 defines standard electrical simulation models for wind turbines and wind power plants. The specified models are time domain positive sequence simulation models, intended to be used in power system and grid stability analyses. The models are applicable for dynamic simulations of short term stability in power systems.

This document defines the generic terms and parameters for the electrical simulation models.

This document specifies electrical simulation models for the generic wind power plant topologies / configurations currently on the market. The wind power plant models include wind turbines, wind power plant control and auxiliary equipment. The wind power plant models are described in a modular way which can be applied for future wind power plant concepts and with different wind turbine concepts.

This document specifies electrical simulation models for the generic wind turbine topologies/concepts/configurations currently on the market. The purpose of the models is to specify the electrical characteristics of a wind turbine at the wind turbine terminals. The wind turbine models are described in a modular way which can be applied for future wind turbine concepts. The specified wind turbine models can either be used in wind power plant models or to represent wind turbines without wind power plant relationships.

The electrical simulation models specified in IEC 61400-27-1 are independent of any 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 61970-301, *Energy management system application program interface (EMS-API) – Part 301: Common information model (CIM) base*

IEC 61970-302, *Energy management system application program interface (EMS-API) – Part 302: Common information model (CIM) dynamics*

3 Terms, definitions, abbreviations and subscripts

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-415 and the following apply.

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>

3.1.1

auxiliary equipment

STATCOM or other device supplementing wind turbines in wind power plant

3.1.2

available power

maximum possible power taking into account wind speed, power rating, rotor speed limits and pitch angle constraints

Note 1 to entry: The aerodynamic power cannot be greater than available power.

3.1.3

base unit

unit of parameter values, which is the per-unit base value if the parameter is given in per-unit or the physical unit if the value is given in a physical unit

3.1.4

fault ride through

ability of a wind turbine or wind power plant to stay connected during voltage dips (under voltage ride through) and voltage swells (over voltage ride through)

3.1.5

generator sign convention

specification of signs for active and reactive components of current and power e.g. from a wind turbine or a reactive power compensation component

Note 1 to entry: The active current and power are positive if power is generated and negative if power is consumed. Likewise, the reactive current and reactive power are positive if reactive power is generated as in the case of a capacitor and negative if reactive power is consumed as in the case of a reactance.

3.1.6

generic model

model that can be adapted to simulate different wind turbines or wind power plants by changing the model parameters

3.1.7

grid variable

voltage, current or frequency

3.1.8

hook

input to or output from a module which is not used in the generic models specified in this standard but may be used to expand generic models beyond the IEC 61400-27-1 scope e.g. to match manufacturer specific models or to match specific national grid connection requirements

3.1.9

integration time step

simulation time interval between two consecutive numerical solutions of the model's differential equations

3.1.10

module

part of a model which has a modular structure

3.1.11

negative (sequence) component (of a three-phase system)

one of the three symmetrical sequence components which exists only in an unsymmetrical three-phase system of sinusoidal quantities and which is defined by the following complex mathematical expression:

$$\underline{X}_2 = \frac{1}{3}(\underline{X}_{L1} + \underline{a}^2 \underline{X}_{L2} + \underline{a} \underline{X}_{L3})$$

where $\underline{a}$ is the 120 degree operator, and $\underline{X}_{L1}$, $\underline{X}_{L2}$ and $\underline{X}_{L3}$ are the complex expressions of the phase quantities concerned, and where $\underline{X}$ denotes the system current or voltage phasors

[SOURCE: IEC 60050-448:1995, 448-11-28]

3.1.12

nominal active power

nominal value of active power which is stated by the manufacturer and is used as per-unit base for all powers (active, reactive, apparent)

[SOURCE: IEC 61400-21-1:2019, 3.15, modified – Removed "wind turbine" from definition]

3.1.13

nominal frequency

nominal value of wind turbine frequency stated by the manufacturer

3.1.14

nominal voltage

nominal value of wind turbine phase-to-phase voltage stated by the manufacturer

3.1.15

over voltage ride through

ability of a wind turbine or wind power plant to stay connected during voltage swells

3.1.16

phasor

complex RMS value

representation of a sinusoidal integral quantity by a complex quantity whose argument is equal to the initial phase and whose modulus is equal to the RMS value

Note 1 to entry: For a quantity $a(t) = \hat{A} \cos(\omega t + \vartheta_0)$ the phasor is $\underline{A} = A \exp(j\vartheta_0)$ where $A = \frac{\hat{A}}{\sqrt{2}}$ is the RMS value and ϑ_0 is the initial phase. A phasor can also be represented graphically.

Note 2 to entry: Electric current phasor $\underline{I}$ and voltage phasor $\underline{U}$ are often used.

Note 3 to entry: The similar representation with the modulus equal to the amplitude is sometimes also called "phasor".

[SOURCE: IEC 60050-103:2017, 103-07-14]

3.1.17

point of connection

reference point on the electric power system where the user's electrical facility is connected

[SOURCE: IEC 60050-617:2009, 617-04-01]

3.1.18**positive (sequence) component** (of a three-phase system)

one of the three symmetrical sequence components which exists in symmetrical and unsymmetrical three-phase system of sinusoidal quantities and which is defined by the following complex mathematical expression:

$$\underline{X}_1 = \frac{1}{3}(\underline{X}_{L1} + \underline{a}\underline{X}_{L2} + \underline{a}^2\underline{X}_{L3})$$

where $\underline{a}$ is the 120 degree operator, and $\underline{X}_{L1}$, $\underline{X}_{L2}$ and $\underline{X}_{L3}$ are the complex expressions of the phase quantities concerned, and where $\underline{X}$ denotes the system current or voltage phasors

[SOURCE: IEC 60050-448:1995, 448-11-27]

3.1.19**power device**

wind turbine or auxiliary equipment

3.1.20**power system stability**

capability of a power system to regain a steady state, characterized by the synchronous operation of the generators after a disturbance due, for example, to variation of power or impedance

Note 1 to entry: IEEE/CIGRE Joint Task Force on Stability Terms and Definitions: Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.

[SOURCE: IEC 60050-603:1986, 603-03-01, modified – addition of Note 1 to entry]

3.1.21**short-circuit power**

product of the current in the short-circuit at a point of a system and a nominal voltage, generally the operating voltage

Note 1 to entry: Using physical units for line current (A) and nominal voltage (V), the product should also include the factor $\sqrt{3}$.

[SOURCE: IEC 60050-601:1985, 601-01-14, modified – "conventional" has been replaced by "nominal"]

3.1.22**short-circuit ratio**

ratio of the short-circuit power at the point of connection to the nominal active power of the wind power plant or wind turbine

3.1.23**steady state of a system**

operating conditions of a network in which the system state variables are considered to be sensibly constant

[SOURCE: IEC 60050-603:1986, 603-02-06]

3.1.24**system state variables**

variable quantities associated with the electrical state of a system

Examples: Voltages, currents, powers, electric charges, magnetic fluxes.

[SOURCE: IEC 60050-603:1986, 603-02-02]

3.1.25

under voltage ride through

ability of a wind turbine or wind power plant to stay connected during voltage dips

3.1.26

voltage dip

sudden voltage reduction at a point in an electric power system, followed by voltage recovery after a short time interval, from a few periods of the sinusoidal wave of the voltage to a few seconds

[SOURCE: IEC 60050-614:2016, 614-01-08]

3.1.27

voltage swell

limited duration non-periodic sudden increase of the power supply network's voltage magnitude above its nominal value and associated change of the phase of the voltage

[SOURCE: IEC 61400-21-1:2019, 3.27]

3.1.28

wind power plant

power station comprising one or more wind turbines, auxiliary equipment and plant control

3.1.29

wind turbine

rotating machinery in which the kinetic wind energy is transformed into another form of energy

[SOURCE: IEC 60050-415:1999,1987, 415-01-01]

3.1.30

wind turbine terminals

point that is part of the wind turbine and identified by the wind turbine manufacturer as a point at which the wind turbine may be connected to the power collection system

[SOURCE: IEC 61400-21-1:2019, 3.25]

3.1.31

zero (sequence) component (of a three-phase system)

one of the three symmetrical sequence components which exists only in an unsymmetrical three-phase system of sinusoidal quantities and which is defined by the following complex mathematical expression:

$$\underline{X}_0 = \frac{1}{3}(\underline{X}_{L1} + \underline{X}_{L2} + \underline{X}_{L3})$$

where $\underline{X}_{L1}$, $\underline{X}_{L2}$ and $\underline{X}_{L3}$ are the complex expressions of the phase quantities concerned, and where $\underline{X}$ denotes the system current or voltage phasors

[SOURCE: IEC 60050-448:1995, 448-11-29]

3.2 Abbreviations and subscripts

3.2.1 Abbreviations

The following abbreviations are used in this document:

ACL aggregated collector line

AG	asynchronous generator
AUX	auxiliary equipment
AUXT	AUX terminals
C	DC link capacitor
CB	circuit breaker
CH	chopper
CIGRE	the International Council on Large Electric Systems
CRB	crowbar
DCL	DC link
DFAG	doubly fed asynchronous generator ³
FRT	fault ride through
GB	gearbox
IEEE	the Institute of Electrical and Electronics Engineers, Inc.
MSC	mechanically switched capacitor bank, which is not switched dynamically during voltage dips
NERC	the North American Electric Reliability Corporation
NLTC	no-load tap changer
OLTC	on-load tap changer
OVRT	over voltage ride through
PD	power device
POC	point of connection of WP
p.u.	per-unit
ROCOF	rate of change of frequency
SCADA	supervisory control and data acquisition
SG	synchronous generator
STATCOM	static synchronous compensator based on a power electronics voltage-source converter
SVC	static var compensator
TR	transformer
TRWP	WP transformer
TRWT	WT transformer
TSC	thyristor switched capacitor bank, which is switched dynamically during voltage dips

³ Often referred to as a doubly-fed induction generator (DFIG), but it is not operated as an induction generator when the rotor current is controlled.

UVRT	under voltage ride through
VRRAG	asynchronous generator with variable rotor resistance
WP	wind power plant
WT	wind turbine
WTR	WT rotor
WTT	WT terminals

3.2.2 Subscripts

0SS	steady state at zero time for initialisation
ACL	aggregated collector line
ag	air gap
AUX	auxiliary equipment
base	per-unit base value
cmd	current command to generator system
Com	communicated variable (output from communication module)
d	delayed
drt	drive train
DTD	active drive train damping
err	controller input error
gen	generator
gs	generator system
init	initial value
filt	filtered variable
FRT	fault ride through
hook	hook
max	maximum
min	minimum
n	nominal
OLTC	on-load tap changer
ord	active or reactive power order from WT controller
p	active component
PD	power device
q	reactive component
ref	controller reference value

sys	power system
TC	torque controller
u	voltage
WTref	WT reference value
UVRT	under voltage ride through
WT	variable at WTT
WTC	grid measurement for the WT controller
WTP	grid measurement for the WP grid protection
WTR	WT rotor

4 Symbols and units

4.1 General

In this document, voltage and current values are positive sequence fundamentals unless otherwise stated.

The symbols used globally in this document are listed in 4.2. Additional symbols used in module block diagram figures in Clause 7 and Annex B represent module parameters which are described in tables adjacent to the figures in the associated module clause. Those symbols are only used locally in the associated module and therefore not duplicated in the symbol list 4.2.

Small letters are used for per-unit variables whereas capital letters are used for variables in physical units. For variables with physical units, the units are given in brackets. For per-unit variables, the per-unit bases are given in the brackets. Currents as well as active and reactive power uses generator sign convention.

4.2 Symbols (units)

φ_{init}	initial phase angle (deg)
Θ	pitch angle (deg)
τ_{init}	initial torque (T_{base})
T_{base}	torque p.u. base value $T_{\text{base}} = \frac{P_{\text{WTn}}}{\Omega_{\text{base}}} \text{ (Nm)}$
ω_{gen}	generator rotational speed (Ω_{base})
ω_{ref}	reference rotational speed (Ω_{base})
ω_{WTR}	WTR rotational speed (Ω_{base})
Ω_{base}	rotational speed p.u. base $\Omega_{\text{base}} = \begin{cases} \Omega_n \text{ (rad/s)} & \text{referring to gen} \\ \frac{\Omega_n}{n_{\text{gear}}} \text{ (rad/s)} & \text{referring to WTR} \end{cases}$
Ω_n	nominal generator rotational speed (rad/s)

f_{AUXPfilt}	filtered grid frequency measurement for AUX grid protection (f_n)
f_n	nominal grid frequency (50 Hz or 60 Hz)
F_{FRT}	fault ride through flag (0,1,2)
F_{OCB}	open-circuit-breaker flag (0,1)
f_{WTCfilt}	filtered grid frequency measurement for WT control (f_n)
f_{WTPfilt}	filtered grid frequency measurement for WT grid protection (f_n)
f_{sys}	global power system grid frequency applied for frequency measurements because angles are calculated in the corresponding stationary reference frame (f_n)
f_{WPfilt}	filtered WP frequency measurement (f_n)
$f_{\text{WPfiltCom}}$	filtered WP frequency measurement communicated to WP (f_n)
F_{WPFRT}	WP fault ride through flag
f_{WT}	WTT grid frequency (f_n)
i_{AUX}	AUXT current phasor in power system coordinates (I_{base})
I_{base}	phase current p.u. base $I_{\text{base}} = \frac{S_{\text{base}}}{\sqrt{3}U_{\text{base}}} \text{ (A)}$
i_{conv}	converter current phasor in power system coordinates (I_{base})
i_{gs}	generator current phasor in power system coordinates (I_{base})
i_{WP}	WP current phasor in power system coordinates (I_{base})
i_{WT}	WTT current phasor in power system coordinates (I_{base})
i_{pcmd}	active current command to generator system (I_{base})
i_{pmax}	maximum active current (I_{base})
i_{qcmd}	reactive current command to generator system (I_{base})
i_{qmax}	maximum reactive current (I_{base})
i_{qmin}	minimum reactive current (I_{base})
J	moment of inertia
n_{gear}	mechanical gear ratio between WTR and generator
p_{ag}	generator (air gap) power (S_{base})
p_{aero}	aerodynamic power (S_{base})
p_{AUXref}	AUX active power reference (S_{base})
p_{PDref}	PD active power reference (S_{base})

p_{PDrefCom}	PD active power reference communicated to PD (S_{base})
p_{init}	initial power (S_{base})
p_{ord}	power order from WT controller (S_{base})
P_{WTn}	nominal active power of WT (W)
P_{WPn}	nominal active power of WP (W)
p_{WPfilt}	filtered WP active power measurement (S_{base})
$p_{\text{WPfiltCom}}$	filtered WP active power measurement communicated to WP (S_{base})
p_{WPPref}	WP active power reference (S_{base})
$p_{\text{WPPrefCom}}$	WP active power reference communicated to WP (S_{base})
p_{WTCfilt}	filtered active power measurement for WT control (S_{base})
p_{WTref}	WTT active power reference (S_{base})
q_{AUXCfilt}	filtered reactive power measurement for AUX control (S_{base})
q_{max}	maximum reactive power (S_{base})
q_{min}	minimum reactive power (S_{base})
q_{WPFilt}	filtered WP reactive power measurement (S_{base})
$q_{\text{WPFiltCom}}$	filtered WP reactive power measurement communicated to WP (S_{base})
q_{WTCfilt}	filtered reactive power measurement for WT control (S_{base})
q_{WTmax}	maximum WTT reactive power (S_{base})
q_{WTmin}	minimum WTT reactive power (S_{base})
r_{rot}	VRRAG rotor resistance (Z_{base})
S_{AUXn}	AUX nominal apparent power (S_{base})
S_{base}	power p.u. base $S_{\text{base}} = \begin{cases} P_{\text{WTn}} \text{ (W)} & \text{referring to WT} \\ S_{\text{AUXn}} \text{ (VA)} & \text{referring to AUX} \\ P_{\text{WPn}} \text{ (W)} & \text{referring to WP} \end{cases}$
T_{s}	integration time step (s)
$\underline{u}_{\text{AUX}}$	AUXT voltage phasor in power system coordinates (U_{AUXn})
u_{AUXCfilt}	filtered voltage measurement for AUX control (U_{base})
U_{AUXn}	nominal phase-to-phase voltage at AUXT (V)
u_{AUXPFilt}	filtered voltage measurement for AUX protection (U_{base})

U_{base}	phase-to-phase voltage p.u. base $U_{base} = \begin{cases} U_{WTn} \text{ (V)} & \text{referring to WT} \\ U_{AUXn} \text{ (V)} & \text{referring to AUX} \\ U_{WPn} \text{ (V)} & \text{referring to WP} \end{cases}$
$\underline{u}_{conv}$	converter voltage phasor in power system coordinates (U_{base})
$\underline{u}_{gs}$	WT generator voltage phasor in power system coordinates (U_{base})
$\underline{u}_{WP}$	WP voltage phasor in power system coordinates (U_{base})
u_{WPfilt}	filtered WP voltage measurement (U_{base})
$u_{WPfiltCom}$	filtered WP voltage measurement communicated to WP (U_{base})
U_{WPn}	nominal phase-to-phase voltage at POC of WP (V)
$\underline{u}_{WT}$	WTT voltage phasor in power system coordinates (U_{base})
u_{WTC}	unfiltered voltage measurement for WT control (U_{base})
$u_{WTCfilt}$	filtered voltage measurement for WT control (U_{base})
U_{WTn}	nominal phase-to-phase voltage at WTT (V)
$u_{WTPfilt}$	filtered voltage measurement for WT grid protection (U_{base})
x_{AUXref}	AUX reactive power reference or delta voltage reference, depending on AUX control mode (x_{base})
x_{base}	reactive power or voltage p.u. base $x_{base} = \begin{cases} S_{base} & \text{in reactive power control mode (VA)} \\ U_{base} & \text{in delta voltage control mode (V)} \end{cases}$
x_{PDref}	PD reactive power reference or delta voltage reference, depending on PD control mode (x_{base})
x_{WPref}	WP reactive power reference or delta voltage reference, depending on WP control mode (x_{base})
$x_{WPrefCom}$	WP reactive power reference or delta voltage reference communicated to WP (x_{base})
x_{WTref}	WTT reactive power reference or delta voltage reference, depending on WT control mode (x_{base})
Z_{base}	impedance base value $Z_{base} = \frac{U_{base}^2}{S_{base}} \text{ (}\Omega\text{)}$

5 Functional specification of models

5.1 General specifications

The models in this document have been developed with the following general specifications⁴ in mind [13]:

- The models are modular in nature to allow for the potential of augmentation in case of future technologies being developed, or future supplemental controls features.
- The models are to be used primarily for power system stability studies and thus should represent all positive sequence dynamics affected and relevant during
 - balanced short-circuits, including faults of varying impedance, on the transmission grid (external to the wind power plant, including voltage recovery),
 - grid frequency disturbances⁵,
 - electromechanical modes of synchronous generator rotor oscillations (typically in the 0,2 Hz to 4 Hz range), and
 - reference value changes.
- The models are for fundamental frequency positive sequence response⁶.
- The models should be valid for typical power system frequency deviations (recommended $\pm 6\%$ from system nominal frequency).
- The models should be able to handle numerically the simulation of phase jumps.
- The models should be valid for steady state voltage deviations within the range from 0,85 p.u. to 1,15 p.u.
- The models should be valid for dynamic voltage phenomena (e.g. faults) where the voltage can dip temporarily close to zero⁷. The equipment suppliers shall establish the minimum voltage dip and/or system conditions for which the model is applicable for their specific equipment. A typical minimum voltage dip is 0,1⁸.
- The typical dynamic simulation time frame of interest is from 10 s to 30 s. Wind speed is assumed to be constant during such a time frame.
- The models should work with integration time steps up to $\frac{1}{4}$ cycle⁹. As a consequence, the bandwidth of the models cannot be greater than 15 Hz¹⁰.
- The models should initialise to a steady state from power flow solutions at full or partial nominal power.
- External conditions like wind speed should be taken into account implicitly through the available power.

⁴ The specifications are not performance requirements of the WPs or WTs, but requirements to the models.

⁵ The WT models do not include frequency control, but simulation of WP frequency control during grid frequency disturbances is possible using the WP power/frequency control model.

⁶ In general, positive sequence simulations are sufficient for bulk power system stability studies. Correct representation of the negative sequence and zero sequence components is cumbersome.

⁷ For very low voltages, the validity is also limited in the case of instability of the converter control [12].

⁸ For comparison, the minimum voltage dip test value in IEC 61400-21:2008 is 0,2.

⁹ The models can run stably with $\frac{1}{2}$ cycle integration time steps, but some time constants may need to be modified to become minimum two times the integration time step. Such parameter modification will affect the model accuracy.

¹⁰ It is generally accepted that the minimum time constant which can be included in a dynamic model is two times the integration time step. Thus, requiring $\frac{1}{4}$ cycle integration time steps, the models should work with integration time steps 0,005 s in the worst (50 Hz) case. The minimum time constant then becomes 0,01 s. For a first order lag with time constant 0,01 s, the 3 dB bandwidth is 10 rad/s = 15,9 Hz, which is rounded down to 15 Hz.

- The models should be numerically stable so that they can be applied in both high and low short-circuit systems. The equipment suppliers shall establish the minimum short-circuit ratio and/or system conditions for which the model is applicable for their specific equipment.
- The models should be clearly specified with block diagrams, explanation of non-linear components and equations in the models, and discussion of any unique initialisation issues to allow for any software vendor to implement the models. The standard will not describe the algorithms that are applied in the specific time series simulation tools, but only the linear, non-linear and differential relations that are modelled.
- The generic models will include generic modules for protection and control systems, which will inevitably deviate from specific manufacturer systems. The models should easily be parameterised to represent any manufacturer specific systems, which will be done by definition of distinct modules for protection and control. This modular structure will make it possible to replace the generic control and protection system modules with manufacturer specific modules.
- The generic models enables modelling of different control options depending on the specified control modes and other control parameters. The included set of control options is optional and specified by the manufacturer. For each of the included control option, the manufacturer shall specify the corresponding control parameters.

5.2 Wind turbine models

The WT models in this document have been developed with the following general specifications in mind:

- The specified wind turbine models can either be used in wind power plant models or to represent wind turbines without wind power plant relationships.
- The standard provides a formal specification of a set of generic simulation models covering the vast majority of existing WT types, and a structure to develop models for future WT types.
- The models span at least the existing four categories of currently developed WT technologies: conventional asynchronous generators, variable rotor resistance asynchronous generators, doubly-fed asynchronous generators and full-converter interface WTs.
- From the point of view of power system studies, existing WTs are generally divided into 4 types A-D [15] or 1-4 [16]. Using the NERC nomenclature 1-4, the 4 types have the following characteristics:
 - Type 1: WT with directly grid connected asynchronous generator with fixed rotor resistance (typically squirrel cage).
 - Type 2: WT with directly grid connected asynchronous generator with variable rotor resistance.
 - Type 3: WT with doubly-fed asynchronous generators (directly connected stator and rotor connected through power converter).
 - Type 4: WT connected to the grid through a full size power converter.
- Over/under frequency and over/under voltage protection should be modelled in order to allow a realistic representation of WT disconnection following grid disturbances.
- The turbine-generator inertia and first drive train torsional mode should be taken into account where it can have significant influence on the power swings¹¹.
- Dynamics of phase-locked loops are not included in the models¹².
- The model should include the reactive power capability of the WT.

¹¹ This is only possible if the eigenfrequency of the first drive train torsional mode is within the bandwidth of the model. However, this is the case for practically all WTs.

¹² Generally, dynamics associated with the PLL are one order of magnitude faster than those of the turbine power controller. The impact of PLL is therefore marginal from a bulk power system studies standpoint.

5.3 Wind power plant models

The WP models in this document have been developed with the following general specifications in mind:

- It is usually sufficient in power system stability studies to use a single aggregated model for all WTs in a WP. It is also possible to simulate a large WP using multiple aggregated models for WTs of the same or of different types. All WT models of the WP shall in this case receive the same reference values from the WP controller.
- The WP controller model measures voltage, frequency, active power and reactive power at the POC and calculates reference signals that are transmitted to the WT models.
- The WP includes two controllers: active power / frequency control and reactive power / voltage control.
- The WP model can control one single POC.
- Reactive power / voltage control is able to regulate power factor, reactive power or voltage. Reactive power and voltage controller models take the limited reactive power capability into account through the limitations in the WT models.
- Power / frequency control regulates active power at the POC as a function of frequency or as a reaction to an external reference change. Active power reference values calculated as a function of the frequency can be absolute (applied to nominal power) or relative (applied to available power). The power control model shall be able to represent the limitations in available power.
- The reactive power / voltage controller and the active power / frequency controller can receive reference values from outside the models as reference changes made by the user.
- Both controllers detect if voltage at POC dips below a threshold value. State variables are frozen if that occurs. Once voltage returns to normal operation band, the controller resumes operation starting from the frozen values or from another specified value.
- Voltage drop compensation shall be provided in the WP model.
- Coordination between WP controllers, OLTC, SVC or other auxiliary controllers at the wind farm level can be implemented in a supervisory controller using the external reference signals to the WP. The modelling of such supervisory controllers is out of the scope of this document.

6 Formal specification of modular structures of models

6.1 General

Clause 6 provides the formal specification of the modular structures of the generic WT, AUX and WP models. This is done in consistency with the functional specifications in Clause 5 and referring to the formal specifications of the modules in Clause 7.

Clause 6 specifies the structure of each generic model using block diagrams. The structure identifies the used modules and input/output variables which are transferred between the modules. The models shall be implemented in a modular way so that each module is available to the user through the input and output variables and the parameters used in each module. Giving access to inputs and outputs from modules makes it possible to use them as part of a modified model, e.g. a manufacturer specific model.

The WT models specified in 6.2 can either be used without an accompanying WP model or as an integral part of the WP model specified in 6.3. In either case, the WT model is intended to be used as an aggregated model representing multiple WTs, but it can also be used to represent a single WT.