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**Wind turbines –
Part 27-1: Electrical simulation models – Wind turbines**

**Eoliennes –
Partie 27-1: Modèles de simulation électrique – Eoliennes**

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INTERNATIONAL STANDARD

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**Wind turbines –
Part 27-1: Electrical simulation models – Wind turbines**

**Eoliennes –
Partie 27-1: Modèles de simulation électrique – Eoliennes**

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WIND TURBINES –

**Part 27-1: Electrical simulation models –
Wind turbines**

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International Standard IEC 61400-27-1 has been prepared IEC Technical Committee 88: Wind turbines.

The text of this draft is based on the following documents:

Enquiry draft	Report on voting
88/510/FDIS	88/529/RVD

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

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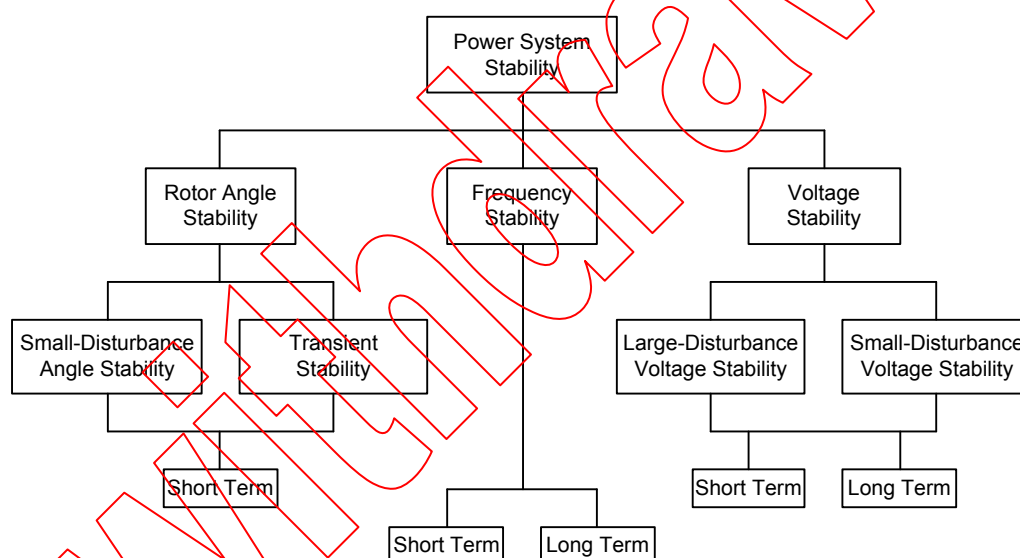
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INTRODUCTION

The IEC 61400-27 series specifies standard dynamic electrical simulation models for wind power generation. IEC 61400-27-1 specifies wind turbine models and model validation procedure. IEC 61400-27-2 will specify wind power plant models and model validation procedure.

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 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 has classified power system stability in categories according to Figure 1.



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

Referring to these categories, the models are developed to represent wind power generation in studies of large-disturbance short term voltage stability phenomena, but they will also be applicable to study other dynamic short term phenomena such as rotor angle stability, frequency stability and small-disturbance voltage stability. 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 as specified in the scope.

The models have to be complete enough to represent the dynamic behaviour at the wind turbine terminals, but must also be suitable for large-scale grid studies. Therefore simplified wind turbine models are specified to perform the typical response of known wind turbine technologies.

The wind turbine models specified in this standard are for fundamental frequency positive sequence response¹. 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 models have not been developed explicitly with eigenvalue calculation (for small signal stability) in mind².
- The models specified here apply only to wind turbines, and therefore do not include wind power plant level controls and additional equipment such as SVCs, STATCOMs and other devices which will be covered by IEC 61400-27-2. The wind turbine models interface to the wind power plant controller models in IEC 61400-27-2.
- This standard does not address the specifics of short-circuit calculations.
- The models are not applicable to studies of extremely weak systems including situations where wind turbines are islanded without other synchronous generation.
- The models are limited by the technical specifications in 5.2.

The validation procedure specified in this standard is intended to be applied to standard models and other fundamental frequency wind turbine models. 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 model³.
- The validation procedure does not specify test and measurement procedures, as it is based on tests specified in IEC 61400-21.
- The simulation model validation is not intended to justify compliance to any grid code requirement, power quality requirements or national legislation.
- The test and measurement procedures introduce errors which limit the possible accuracy as specified in the validation procedure.
- The validation procedure does not include steady state validation, but focuses on validation of the dynamic performance of the model.

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

- 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.

¹ This standard is dealing with balanced as well as unbalanced faults, but for unbalanced faults, only the positive sequence components are specified.

² These wind generation systems are highly non-linear and simplifications have been made in the development of the proposed models. Thus, linearisation for eigenvalue analysis is not trivial nor necessarily appropriate based on these simplified models.

³ Clause 6 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 B describes limits to the possible accuracy of the models.

- 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.
- Education and research communities, who can also benefit from the generic models, as the manufacturer specific models are typically confidential.

Withdrawn

WIND TURBINES –

Part 27-1: Electrical simulation models – Wind turbines

1 Scope

IEC 61400-27 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. IEC 61400-27 includes procedures for validation of the specified electrical simulation models. The validation procedure for IEC 61400-27 is based on tests specified in IEC 61400-21.

IEC 61400-27 consists of two parts with the following scope:

- IEC 61400-27-1 specifies dynamic simulation models for generic wind turbine topologies/ concepts / configurations on the market. IEC 61400-27-1 defines the generic terms and parameters with the purpose of specifying the electrical characteristics of a wind turbine at the connection terminals. The models are described in a modular way which can be applied for future wind turbine concepts. The dynamic simulation models refer to the wind turbine terminals. The validation procedure specified in IEC 61400-27-1 focuses on the IEC 61400-21 tests for response to voltage dips, reference point changes and grid protection.
- IEC 61400-27-2 specifies dynamic simulation models for the generic wind power plant topologies / configurations on the market including wind power plant control and auxiliary equipment. In addition IEC 61400-27-2 specifies a method to create models for future wind power plant configurations. The wind power plant models are based on the wind turbine models specified in IEC 61400-27-1.

The electrical simulation models specified in IEC 61400-27 are independent of any software simulation tool.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050, *International electrotechnical vocabulary*

IEC 61400-21, *Wind turbines – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines*

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, as well as the following apply:

3.1.1**available aerodynamic power**

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

3.1.2**generic model**

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

3.1.3**integration time step**

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

3.1.4**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

Note 1 to entry: Negative sequence voltage or current components may be significant only when the voltages or currents, respectively, are unbalanced. For example, if phase voltage phasors are symmetrical $\underline{U}_{L1} = Ue^{j\theta}$, $\underline{U}_{L2} = Ue^{j(\theta+4\pi/3)}$ and $\underline{U}_{L3} = Ue^{j(\theta+2\pi/3)}$ then $\underline{U}_2 = (Ue^{j\theta} + e^{j4\pi/3} Ue^{j(\theta+4\pi/3)} + e^{j2\pi/3} Ue^{j(\theta+2\pi/3)})/3 = Ue^{j\theta} (1 + e^{j2\pi/3} + e^{j4\pi/3})/3 = 0$.

[SOURCE: IEC 60050-448:1995, 448-11-28, modified (addition of Note 1 to entry)]

3.1.5**nominal active power**

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

3.1.6**nominal current**

nominal value I_n of wind turbine current, which must be calculated from nominal active power

P_n and nominal voltage U_n according to $I_n = \frac{P_n}{\sqrt{3}U_n}$

3.1.7**nominal frequency**

nominal value of wind turbine frequency, which must be stated by the manufacturer

3.1.8**nominal voltage**

nominal value of wind turbine voltage, which must be stated by the manufacturer

3.1.9 phasor complex rms value

for a sinusoidal quantity $a(t) = \hat{A} \cos(\omega t + \nu_0)$, complex value $\underline{A} = A e^{j\nu_0}$ with $A = \frac{\hat{A}}{\sqrt{2}}$, where j is the imaginary unit, $\hat{A}$ is complex amplitude, ω is angular frequency, and ν_0 is initial phase

[SOURCE: IEC 60050-103:2009 103-07-14]

3.1.10 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]

3.1.11

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

one of the three symmetrical sequence components which exists only 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]

3.1.12

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]

3.1.13

quasi steady state of a system

short-term steady state, for instance during a voltage dip which is long enough to include a period where the system state variables can be considered sensibly constant.

3.1.14

reaction time

elapsed time from the issue of a step change command until the observed value reaches 10 % of the step change

Note 1 to entry: Reaction time is illustrated in Figure 2.

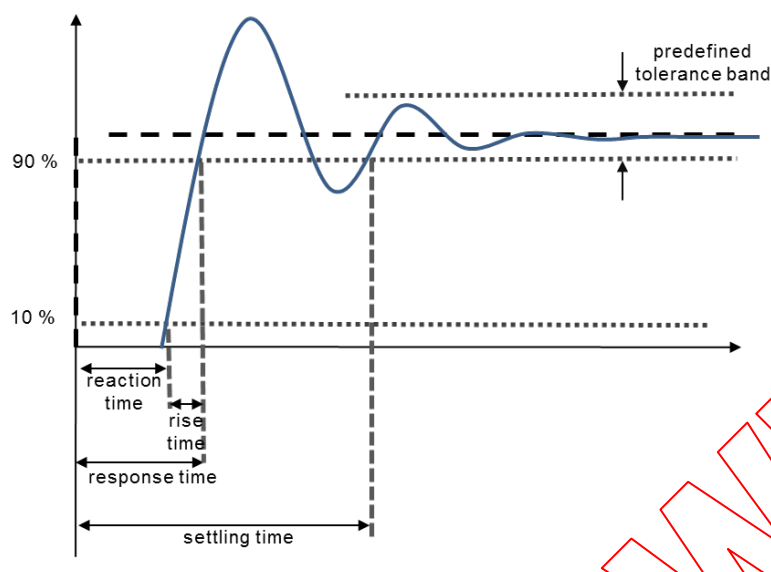


Figure 2 – Example of step response.

3.1.15 response time

elapsed time from the issue of a step change command until the observed value first time enters the predefined tolerance band of the target value

Note 1 to entry: Response time is illustrated in Figure 2.

3.1.16 settling time

elapsed time from the issue of a step change command until the observed value continuously stays within the predefined tolerance band of the target value

Note 1 to entry: Settling time is illustrated in Figure 2.

3.1.17 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]

3.1.18 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

3.1.19 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]

3.1.20

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]

3.1.21

transient time period

time periods with measured electromagnetic transients which are not included in fundamental frequency models

3.1.22

unbalance factor

in a three-phase system, the degree of unbalance expressed by the ratio (in per cent) between the r.m.s. values of the negative sequence (or the zero sequence) component and the positive sequence component of voltage or current

[SOURCE: IEC 60050-604:1987, 604-01-30]

3.1.23

under voltage ride through UVRT

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

3.1.24

voltage dip

sudden reduction of the voltage at a point in the system, followed by voltage recovery after a short period of time, from a few cycles to a few seconds

[SOURCE: IEC 60050-604:1987, 604-01-25]

3.1.25

wind power plant

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

3.1.26

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]

3.1.27

wind turbine terminals

a point being a part of the wind turbine and identified by the wind turbine supplier at which the wind turbine is connected to the power collection system

Note 1 to entry: Same definition as in IEC 61400-21 defining the measurement point of the tests.

3.1.28

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:

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

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 standard:

AG	asynchronous generator
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 ⁴
GB	gearbox
GSC	generator side converter
IEEE	the Institute of Electrical and Electronics Engineers, Inc.
LSC	line (grid) side converter
MSC	mechanically switched capacitor bank, which is not switched dynamically during voltage dips
NERC	the North American Electric Reliability Corporation
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
TSC	thyristor switched capacitor bank, which is switched dynamically during voltage dips
UVRT	under voltage ride through

⁴ 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.

VRRAG	asynchronous generator with variable rotor resistance
WP	wind power plant
WT	wind turbine
WTR	WT rotor
WTT	WT terminals

3.2.2 Subscripts

ag	air gap
base	per-unit base value
cmd	current command to generator system
drt	drive train
DTD	active drive train damping
E	error between simulation and measurement
err	controller input error
gen	generator
init	initial value
filt	filtered
MAE	mean absolute error between simulation and measurement
max	maximum
ME	mean error between simulation and measurement
mea	measured
min	minimum
MXE	maximum error between simulation and measurement
n	nominal
ord	active or reactive power order from WT controller
p	active component
q	reactive component
u	voltage
WTref	WT reference value
sim	simulated
UVRT	under voltage ride through
WT	variable at WTT
WTR	WT rotor

4 Symbols and units

4.1 General

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

The following symbols are used in this standard in addition to the parameters defined in the module library 5.6. For variables with physical units, the units are given in brackets. For per-unit variables, the per-unit bases are given in the brackets.

4.2 Symbols (units)

Θ	pitch angle (deg)
τ_{init}	initial value of torque (T_{base})
T_{base}	torque p.u. base value $T_{\text{base}} = \frac{P_n}{\Omega_{\text{base}}} \text{ (Nm)}$
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 $\Omega_{\text{base}} = \left\{ \begin{array}{l} \Omega_n \text{ referring to gen} \\ \frac{\Omega_n}{n_{\text{gear}}} \text{ referring to WTR} \end{array} \right\} \text{ (rad/s)}$
Ω_n	nominal generator rotational speed (rad/s)
f_n	nominal grid frequency (50 Hz or 60 Hz)
F_{OCB}	open-circuit-breaker flag (0,1)
F_{UVRT}	under voltage ride through flag (0,1,2)
f_{sys}	global power system grid frequency (f_n)
f_{WT}	WTT grid frequency (f_n)
I_n	nominal current at WTT (A)
i_{gen}	generator current phasor in power system coordinates (I_n)
i_{WT}	WTT current phasor in power system coordinates (I_n)
i_{WTmea}	measured and signal processed WTT current (I_n)
i_{WTraw}	raw WTT current measured according to IEC 61400-21 (I_n)
i_{WTsim}	simulated and signal processed WTT current (I_n)
i_{pcmd}	active current command to generator system (generation sign convention) (I_n)
i_{pmax}	maximum active current (generation sign convention) (I_n)
i_{qcmd}	reactive current command to generator system (capacitive sign convention) (I_n)
i_{qmax}	maximum reactive current (capacitive sign convention) (I_n)

i_{qmin}	minimum reactive current (capacitive sign convention) (I_n)
n_{gear}	mechanical gear ratio between WTR and generator
p_{ag}	generator (air gap) power (P_n)
p_{aero}	aerodynamic power (P_n)
p_{ord}	power order from WT controller (P_n)
P_n	nominal active power of WT (W)
p_{WT}	WTT active power (generation sign convention) (P_n)
p_{WTref}	WTT active power reference (P_n)
q_{WT}	WTT reactive power (capacitive sign convention) (P_n)
q_{WTmax}	maximum WTT reactive power (capacitive sign convention) (P_n)
q_{WTmin}	minimum WTT reactive power (capacitive sign convention) (P_n)
r_{rot}	VRRAG rotor resistance (Z_{base})
T_{com}	common sample time used to compare measured and simulated values (s)
T_{mea}	sample rate of raw measured data (s)
T_s	integration time step (s)
$\underline{u}_{gen}$	generator voltage phasor in power system coordinates (I_n)
U_n	nominal phase-to-phase voltage at WTT (V)
u_{WT}	WTT voltage (U_n)
$\underline{u}_{WT}$	WTT voltage phasor in power system coordinates (U_n)
u_{WTmea}	measured and signal processed WTT voltage (U_n)
u_{WTraw}	raw WTT voltage measured according to IEC 61400-21 (U_n)
u_{WTsim}	simulated and signal processed WTT voltage (U_n)
W_{fault}	time window defining the fault period (s)
$W_{faultQS}$	quasi steady state part of W_{fault} (s)
W_{post}	time window defining the post-fault period (s)
W_{postQS}	quasi steady state part of W_{post} (s)
W_{pre}	time window defining the pre-fault period (s)
$x_E(n)$	simulation error time series provided by signal processing
x_{MAE}	mean absolute error in time window
x_{ME}	mean error in time window
$x_{mea}(n)$	measured time series provided by signal processing
x_{MXE}	maximum error in time window
$x_{sim}(n)$	simulated time series provided by signal processing

x_{WTref} WTT reactive power reference (capacitive sign convention) or delta voltage reference, depending on WT control mode (P_n or U_n)

Z_{base} impedance base value $Z_{base} = \frac{U_n^2}{P_n} (\Omega)$

5 Specification of models

5.1 Overview

The objective of Clause 5 is to specify a set of generic simulation models covering the existing WT types, and a structure to develop models for future WT types.

WTs are generally divided into 4 types, which are currently significant in power systems (Hansen 2004, NERC 2010). Using the NERC nomenclature (type 1 to 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.

The model specification is organised in the following subclauses:

- 5.2 gives the general specifications.
- 5.3 specifies the interface between the WT model, WP model and the grid model.
- 5.4 specifies categories of WT model parameters and how these categories are affecting the model initialisation.
- 5.5 specifies the generic modular structure of WT models modular structure for type 1 to 4 models respectively and for the corresponding control models.
- 5.6 specifies the detailed models for the individual modules used in 5.5.

5.2 General specifications

This subclause describes the general specifications for the WT models. The specifications are not performance requirements of the WTs, but requirements to model structure.

These models have been developed with the following specifications in mind:

- 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.
- 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 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 ± 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 typical dynamic simulation time frame of interest is from 10 seconds to 30 seconds. Wind speed is assumed to be constant during such a time frame.
 - The models should work with integration time steps up to $\frac{1}{4}$ cycle⁸. As a consequence, the bandwidth of the models cannot be greater than 15 Hz⁹.
 - The models should initialize 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 aerodynamic power.
 - Over/under frequency and over/under voltage protection should be modelled where it exists in the control in order to allow a realistic representation of WT disconnection following grid disturbances. This may be separate modules that connect to the main WT model¹⁰.
 - 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.
 - The models should be numerically sound 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. Dynamics of phase-locked loops are not included in the models¹².

⁵ Frequency control is not included in the WT models in IEC 61400-27-1. Primary frequency control is included in the plant level models specified in the informative Annex D, and will be included in the plant level models specified in IEC 61400-27-2.

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 The models are not validated for dynamic overvoltage events. For very low voltages, the validity is also limited in the case of instability of the converter control (Göksu 2014)

⁸ 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.

⁹ 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.

¹⁰ The specified fundamental frequency models do not reflect any grid protection faster than 1 cycle.

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.

- The models should be clearly specified with block diagrams, explanation of non-linear components and equations in the models, and discussion of any unique initialization 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 models 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 blocks for protection and control. This structure will make it possible to replace the generic control and protection system blocks with manufacturer specific blocks.
- The model should include the reactive power capability of the WT.

5.3 Model interface

The purpose of this subclause is to specify the interface of the WT models. The WT model interfaces to the grid model in the power system simulation tool and to the WP model specified in IEC 61400-27-2.

The general dynamic simulation interface between WT model, grid model and WP model is illustrated in Figure 3.

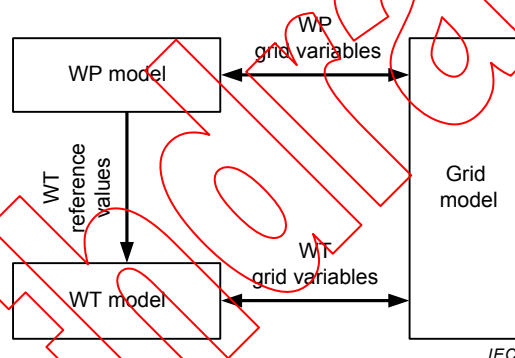


Figure 3 – General interface between WT model, grid model and WP model

The model can either be excited by an event in the grid model such as a short-circuit, or by a change in a WT reference value from the WP controller.

The WT model takes the grid voltages as input from the grid model and gives the grid currents as output. These inputs and outputs refer to WTT.

WTs can receive online reference values, typically via the wind power plant SCADA system from a wind power plant controller or from a remote control. The available set of reference values is different, depending on the WT type, the WT manufacturer and operation mode. The following reference values are considered in the generic WT models:

- Active power reference value.
- Reactive power reference value.
- Voltage reference value.

Note that the WT models can also simulate power factor control mode, but in that case, it is assumed that the power factor reference value of the WT is constant throughout the simulation.

5.4 Parameters and initialisation

5.4.1 General

In order to use one of the generic models specified in 5.5, the WT manufacturer shall supply the WT model parameters for each of the used modules identified in the table for the selected model type. The global WT model parameters are identified and described in 5.4.3, but the majority of the WT model parameters are identified and described in the tables of parameters in the module library 5.6. These WT model parameters are categorized according to 5.4.2.

Some of the modules described in 5.6 also use initialisation variables, which are set by the model initialisation, typically depending on the load flow case. 5.4.4 provides an overview of the initialisation.

5.4.2 Parameter categories

Each WT model parameter is categorised as type dependent, project dependent, or case dependent. The category of each WT model parameter is identified in the tables of parameters in the module library 5.6.

The three parameter categories are defined as follows:

- Type dependent parameters are characteristic to the specific WT type. This is typically the case for mechanical and electrical parameters.
- Project dependent parameters may be different for a specific WT type, depending on the specific project. This is typically the case for control parameters set according to specific grid code requirements.
- Case dependent parameters may vary depending on the specific steady state prior to the disturbance, e.g. depending on if the actual and / or possible power is nominal or partial. It is the responsibility of the WT manufacturer to specify clearly how case dependent parameters depend on the specific simulation case.

The WT manufacturer may upgrade the category of specific parameters specified in the tables in 5.6 whenever this is valid to the specific WT type. It is the intention to reduce the number of case dependent parameters to a minimum, but also be clear in stating the limited application range for a specific set of parameters.

5.4.3 Global parameters

The global WT model parameters are listed in Table 1. Those parameters are used in the module library 5.6 and the block symbol library Annex G in addition to the module specific parameters listed in each of the individual models in 5.6.

Table 1 – Global WT model parameters

Symbol	Base unit	Description
f_n	Hz	Nominal frequency
T_s	s	Integration time step

5.4.4 Initialisation

The initialisation of the WT model must be done in consistency with the initialisation of the grid model and the wind power plant model specified in IEC-61400-27-2. The interface of the initialisation of grid model, wind power plant model and WT model is illustrated in Figure 4.

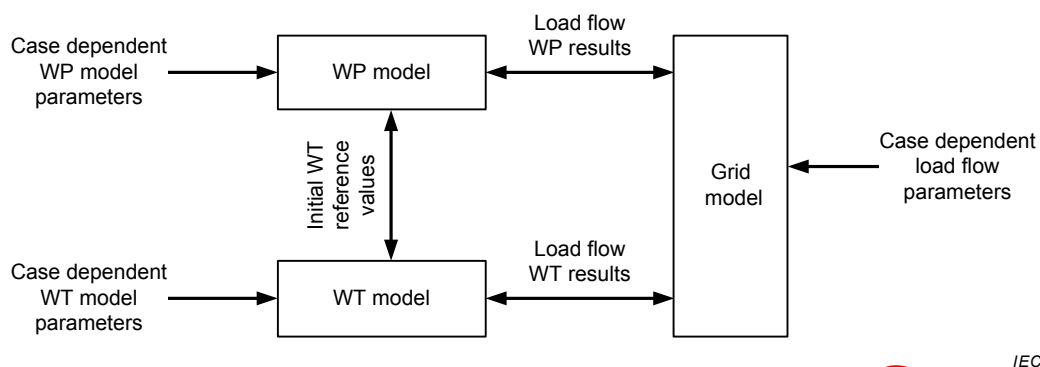


Figure 4 – General interface for initialisation of WT model, WP model and grid model.

Prior to the model initialisation, the case dependent parameters must be updated. This applies to load flow parameters in the grid model and to case specific WT and WP parameters.

The grid model is initialised by a load flow, which must be set to agree with the control modes in the wind power plant model and the WT model. The load flow will affect the initialisation of the wind power plant model and WT model, because the load flow determines all initial voltages and currents. Also, depending on the initial reference values, the initialisation of the wind power plant model may influence the initialisation of the WT model.

Table 2 lists the initialisation variables which are explicitly used in the models

Table 2 – Initialisation variable used explicitly in model block diagrams

Symbol	Base unit	Description
p_{init}	P_n	Initial power
τ_{init}	T_{base}	Initial steady state drive train torque
$\tan(\varphi_{init})$	-	Power scaling factor used in power factor control

5.5 Modular structure of models

5.5.1 Generic modular structure

This standard uses the generic modular structure of the WT model shown in Figure 5. The structure is consistent with the interface of the WT model defined in Figure 3. The horizontal sequence of blocks in the middle reflects the conversion of aerodynamic power to electrical power at the WTTs, while protection and control is shown above and below respectively.

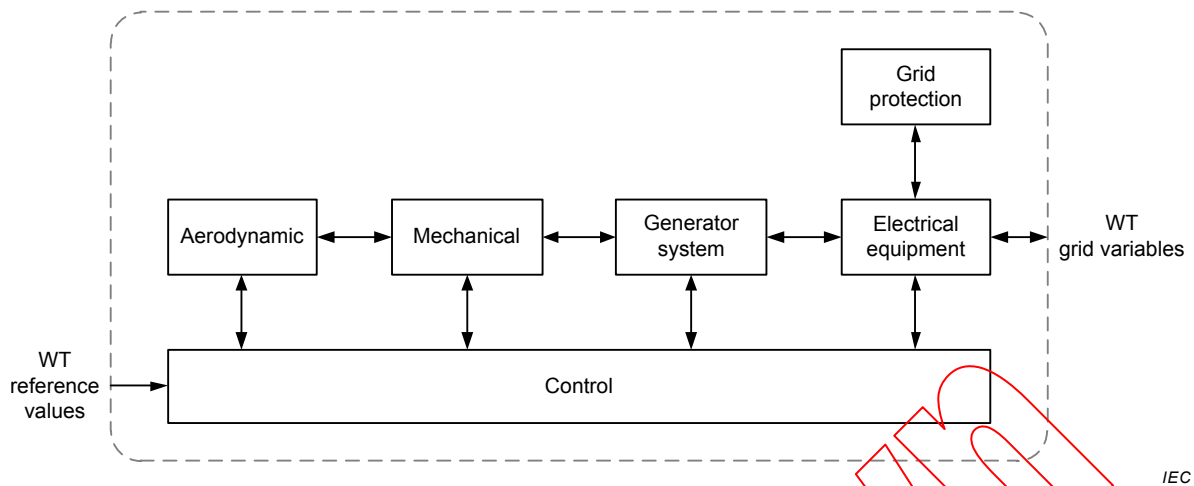


Figure 5 – Generic modular structure of WT models

5.5.2 Type 1

5.5.2.1 Definition of type 1

The type 1 WT uses asynchronous generators directly connected to the grid, i.e. without power converter. Most Type 1 WTs have a soft-starter, but this is only active during start-up.

Figure 6 shows the main electrical and mechanical components which are included in the type 1 WT models. The WT rotor (WTR) is connected to the asynchronous generator (AG) via a gearbox (GB). The capacitor bank provides reactive power compensation. Most type 1 WTs are equipped with mechanically switched capacitor banks (MSC), which are considered fixed for short term simulations. Type 1 WTs with fault-ride-through capabilities typically use thyristor switched capacitor bank (TSC) which is dynamically controlled during and after faults. The main circuit breaker (CB) disconnects generator and capacitors simultaneously. WTT can be on either side of the transformer (TR) as stated in IEC 61400-21.

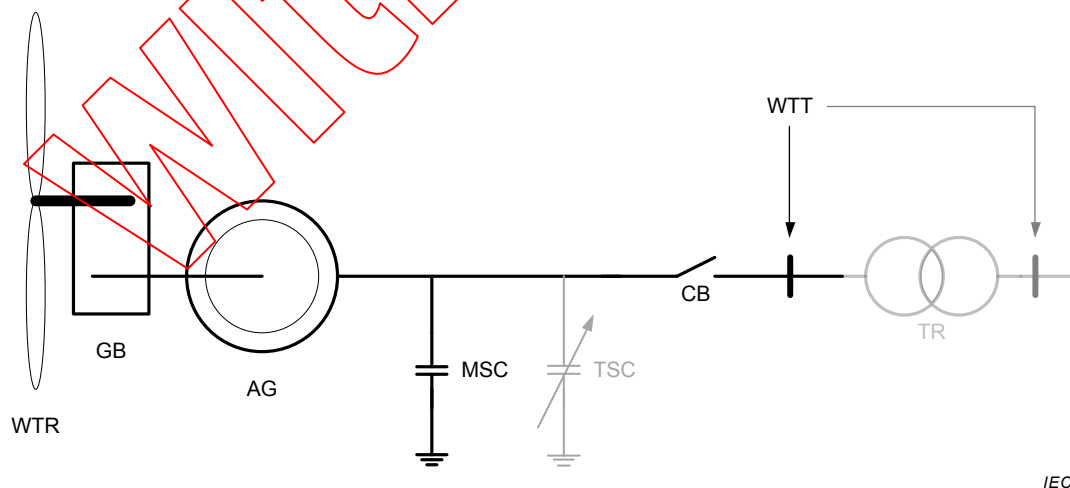


Figure 6 – Main electrical and mechanical components of type 1 WTs

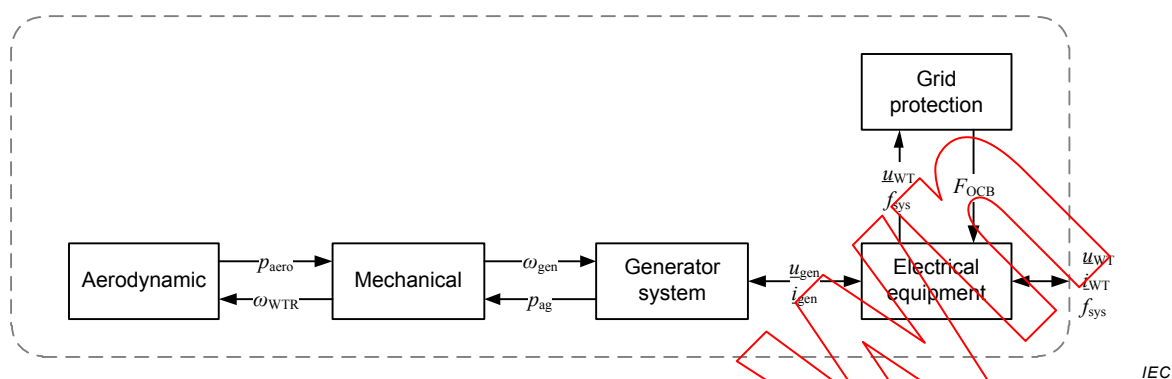
Type 1 WTs may have fixed blade pitch angles or pitch systems allowing the blades to be turned away from stall (positive pitch angle) or into stall (negative pitch angle, also denoted active power control or Combi Stall control). The blade angle control is in some type 1 WTs used in active UVRT control.

Therefore, two type 1 models are specified in 6.5.5.2 and 6.5.5.3:

- Type 1A: WTs with fixed pitch angle
- Type 1B: WTs with UVRT pitch angle control

5.5.2.2 Model specification of type 1A

Figure 7 shows the modular structure for the type 1A WT model. This model assumes that the pitch angle is fixed.



NOTE The aerodynamic block is included in the figure, but it only represents a simplistic constant aerodynamics torque model.

Figure 7 – Modular structure for the type 1A WT model

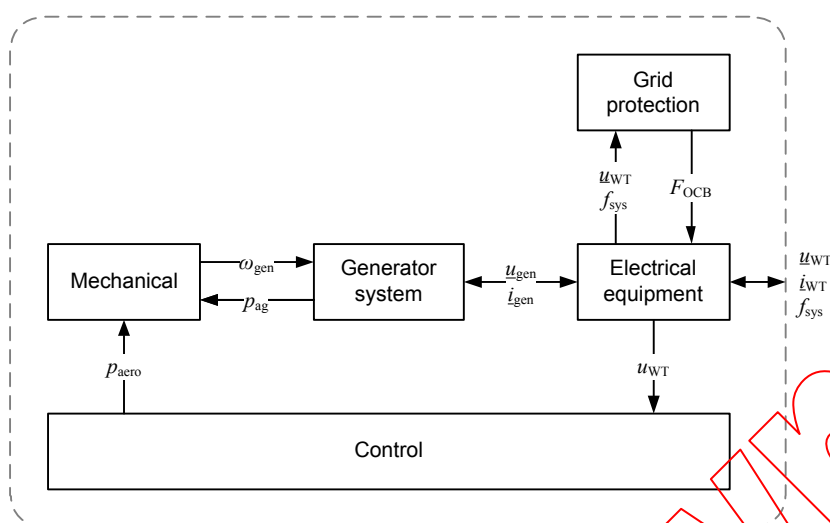
The details for each block are given in the Modules referred to in Table 3.

Table 3 – Modules used in type 1A model

Block	Module clause	Module name
Aerodynamic	5.6.1.1	"Constant aerodynamic torque model"
Mechanical	5.6.2.1	"Two mass model"
Generator system	5.6.3.1	"Asynchronous generator model"
Electrical equipment	5.6.4.1	"Shunt capacitor model"
	5.6.4.2	"Circuit breaker model"
	(5.6.4.3)	("Transformer model")
Grid protection	5.6.6	"Grid protection model"

5.5.2.3 Model specification of type 1B

Figure 8 shows the modular structure for the type 1B WT model. This model includes UVRT pitch angle control.



NOTE The aerodynamic block is not included in the figure because the aerodynamic effects are embedded in the control model.

Figure 8 – Modular structure for the type 1B WT model

The details for each block are given in the Modules referred to in Table 4.

Table 4 – Modules used in type 1B model

Block	Module clause	Module name
Aerodynamic	5.6.1.1	"Constant aerodynamic torque model"
Mechanical	5.6.2.1	"Two mass model"
Generator system	5.6.3.1	"Asynchronous generator model"
Electrical equipment	5.6.4.1	"Shunt capacitor model"
	5.6.4.2	"Circuit breaker model"
	(5.6.4.3)	("Transformer model")
Control	5.6.5.1	"Pitch control power model" "
Grid protection	5.6.6	"Grid protection model"

5.5.3 Type 2

5.5.3.1 Definition of type 2

Figure 9 shows the main electrical and mechanical components which are considered in the type 2 WT model. A type 2 WT is similar to a type 1 WT in many aspects, but the type 2 turbine is equipped with a variable rotor resistance (VRR) and therefore uses a variable rotor resistance asynchronous generator (VRRAG). Type 2 WTs are also normally equipped with blade angle control.

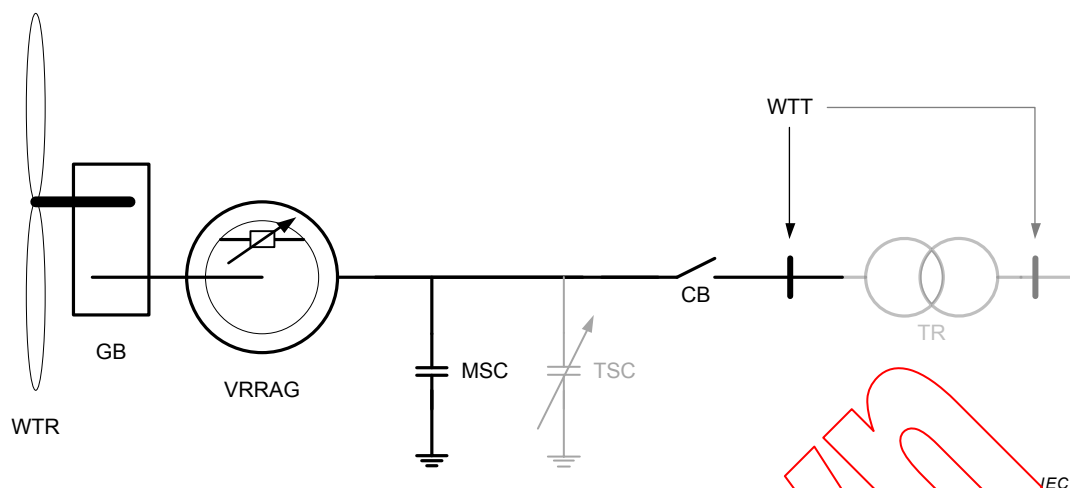
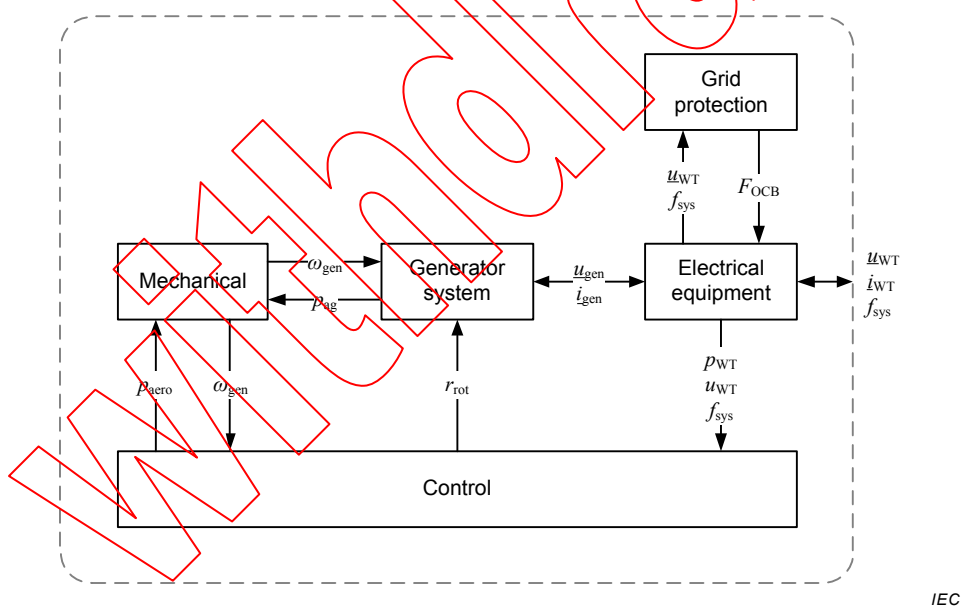


Figure 9 – Main electrical and mechanical components of type 2 WTs

5.5.3.2 Model specification of type 2

The type 2 model specified in this standard is based on the generic WT models specified by the IEEE / WECC working group and used in the 2nd generation WECC models (Pourbeik 2013). The modular structure for the type 2 WT model is shown in Figure 10.



NOTE The aerodynamic block is not included in the figure because the aerodynamic effects are embedded in the control model.

Figure 10 – Modular structure for the type 2 WT model

Figure 11 shows the modular structure for the type 2 control model. It uses the “Pitch control emulator” module to control active power supplemented by the rotor resistance control model, and passes the reactive power or voltage control reference x_{WTref} to the shunt capacitor model in the electrical equipment module.

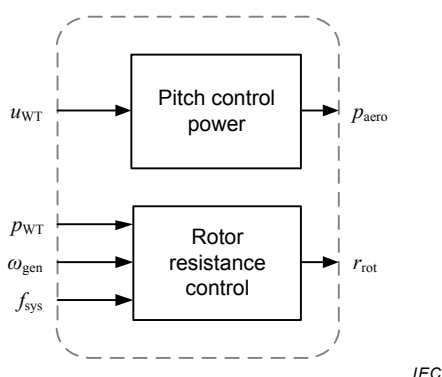


Figure 11 – Modular structure for the type 2 control model

The details for each block are given in the Modules referred to in Table 5.

Table 5 – Modules used in type 2 model

Block	Module clause	Module name
Mechanical	5.6.2.1	"Two mass model"
Generator system	5.6.3.1	"Asynchronous generator model"
Electrical equipment	5.6.4.1	"Shunt capacitor model"
	5.6.4.2	"Circuit breaker model"
	(5.6.4.3)	("Transformer model")
Control	5.6.5.1	"Pitch control power model"
	5.6.5.3	"Rotor resistance control model"
Grid protection	5.6.6	"Grid protection model"

5.5.4 Type 3

5.5.4.1 Definition of type 3

A type 3 WT uses a doubly fed asynchronous generator (DFAG), where the stator is directly connected to the grid and the rotor is connected through a back-to-back power converter. Figure 12 shows the main electrical and mechanical components which are considered in the type 3 WT models in this standard. The power converter consists of the generator side converter (GSC), the line side converter (LSC) and the DC link (DCL) with the DCL capacitor (C). Type 3 WTs can have sufficiently dimensioned GSC and chopper (CH) for voltage ride-through without bypassing or disconnecting the converter. Others type 3 WTs include a crowbar device (CRB) which short-circuits the rotor during electromagnetic transients and converts the WT generator during this time into an induction machine.

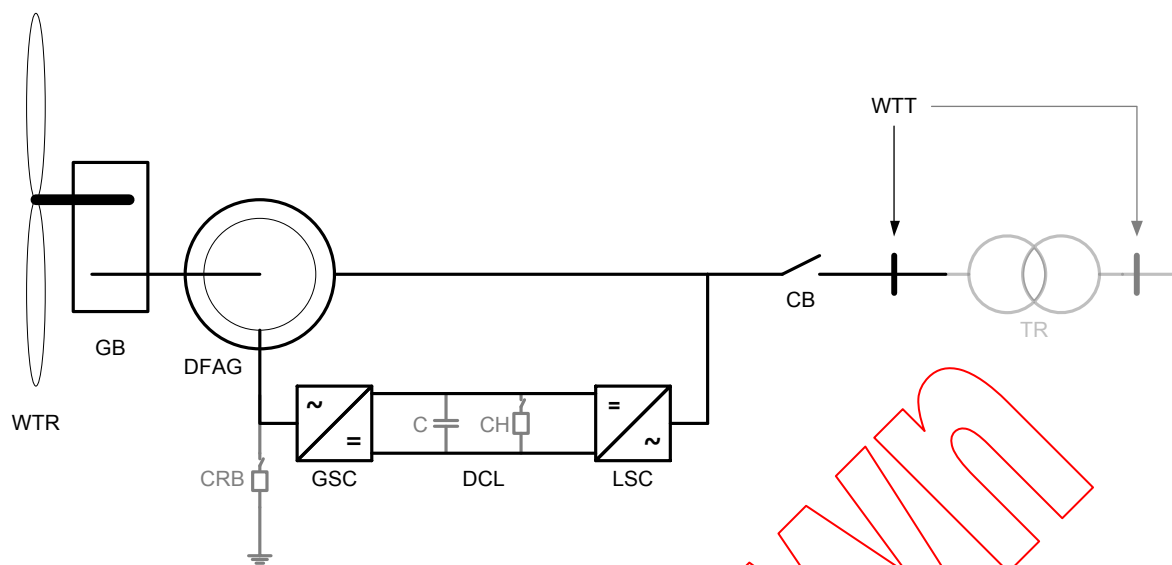


Figure 12 – Main electrical and mechanical components of type 3 WTs

5.5.4.2 Model specification of type 3

The generic type 3 model specified in this clause includes modules for the mechanical system as well as the aerodynamics. This level of detail is not always needed. In some cases, one of the generic type 4 models will be sufficient to simulate the behaviour at the WT terminals.

The modular structure for the type 3 WT model is shown in Figure 13.

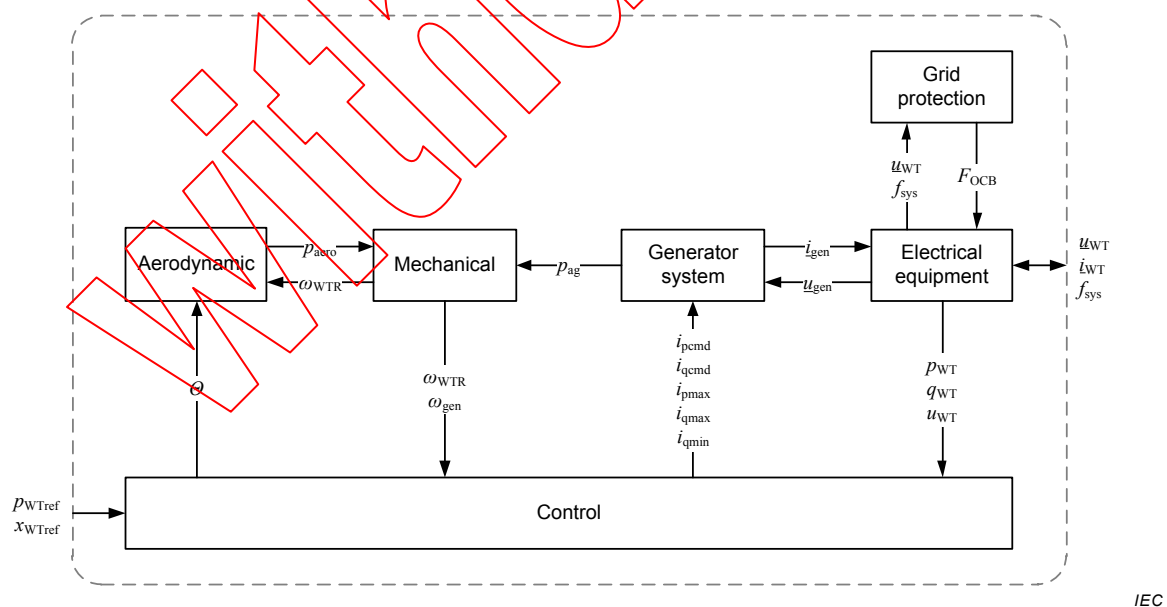


Figure 13 – Modular structure for the type 3 WT model

Figure 14 shows the modular structure for the type 3 control models.

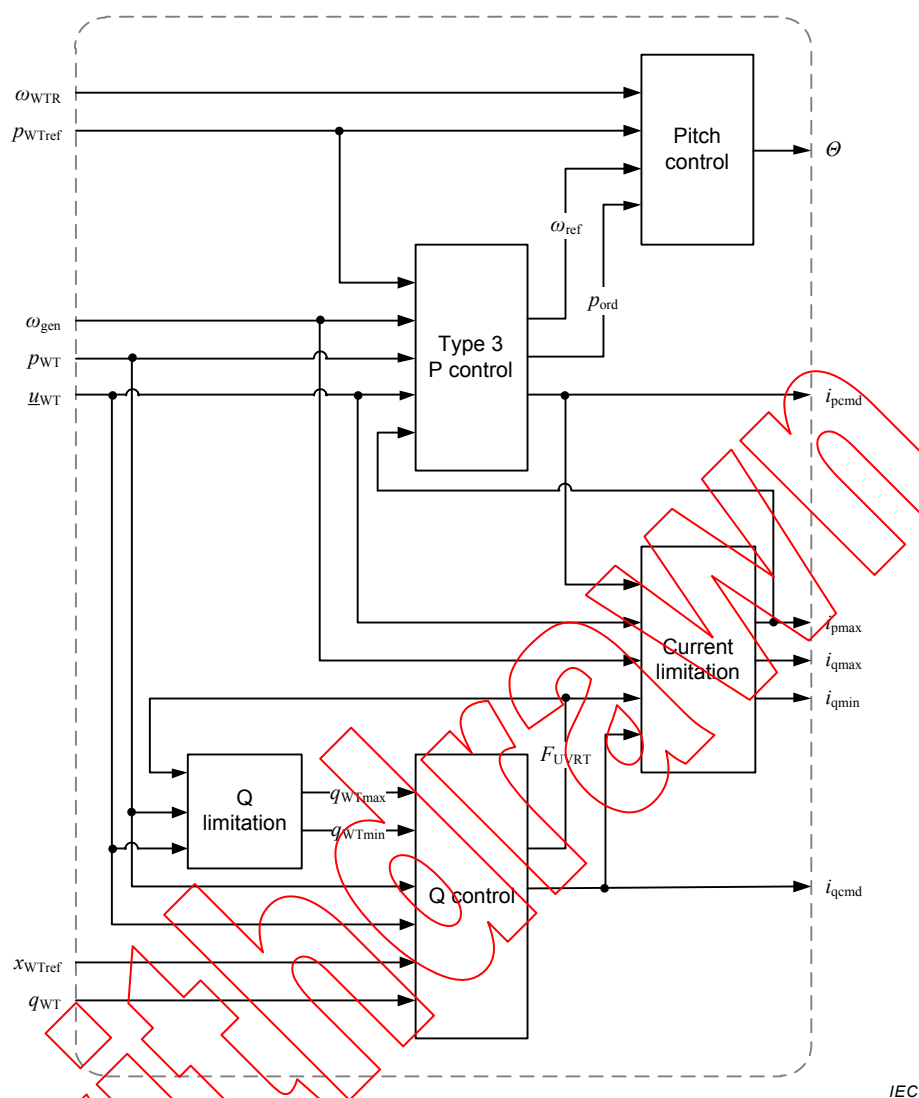


Figure 14 – Modular structure for the type 3 control models

The details for each block are given in the Modules referred to in Table 6.

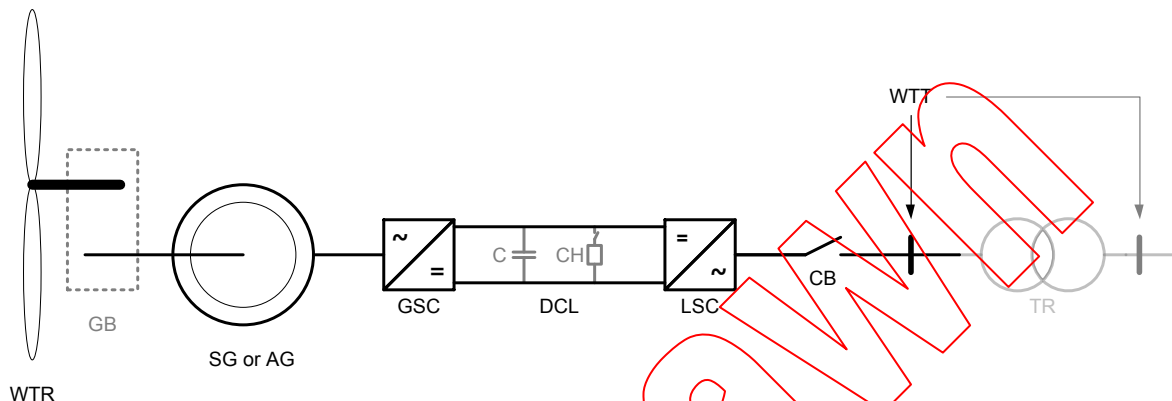
Table 6 – Modules used in type 3 model

Block	Module clause	Module name
Aerodynamic	5.6.1.3	"Two-dimensional aerodynamic model" or "One-dimensional aerodynamic model"
Mechanical	5.6.2.1	"Two mass model"
Generator system	5.6.3.2 or 5.6.3.3	"Type 3A generator set model" or "Type 3B generator set model"
Electrical equipment	5.6.4.2 (5.6.4.3)	"Circuit breaker model" ("Transformer model")
Control	5.6.5.4 5.6.5.7 5.6.5.8 5.6.5.9 or 5.6.5.10 5.6.5.2	"P control model type 3" "Q control model" "Current limitation model" "Constant Q limitation model" or "QP and QU limitation model" "Pitch angle control model"
Grid protection	5.6.6	"Grid protection model"

5.5.5 Type 4

5.5.5.1 Definition of type 4

Type 4 WTs are WTs connected to the grid through a full scale power converter. Figure 15 shows the main electrical and mechanical components which are considered in the type 4 WT models in this standard. Type 4 WTs use either synchronous generators (SG) or asynchronous generators (AG). Some type 4 WTs use direct drive synchronous generators, and therefore have no gearbox.



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Figure 15 – Main electrical and mechanical components of type 4 WTs

Type 4 WTs with choppers can normally be modelled neglecting the aerodynamic and mechanical parts of the WT. Type 4 WTs without choppers inject post-fault power oscillations due to damping of torsional oscillations. This is also the case for type 4 WTs with partially rated choppers. These oscillations are normally not affecting the power system stability, but the effect of torsional oscillation damping may be included using a two-mass mechanical model. If partially rated chopper is applied, then the damping coefficient in the two-mass model can be adjusted to match the rating of the chopper. The type 3A model may be used to simulate type 4 WTs, but simplified models are usually sufficient because of the converter decoupling of the drive train from the grid.

Therefore, two type 4 models are specified in 6.5.5.2 and 6.5.5.3:

- Type 4A: a model neglecting the aerodynamic and mechanical parts and thus not simulating any power oscillations
- Type 4B: a model including a 2-mass mechanical model to replicate the power oscillations but assuming constant aerodynamic torque

5.5.5.2 Type 4A model specification

The modular structure for the type 4A WT model is shown in Figure 16.

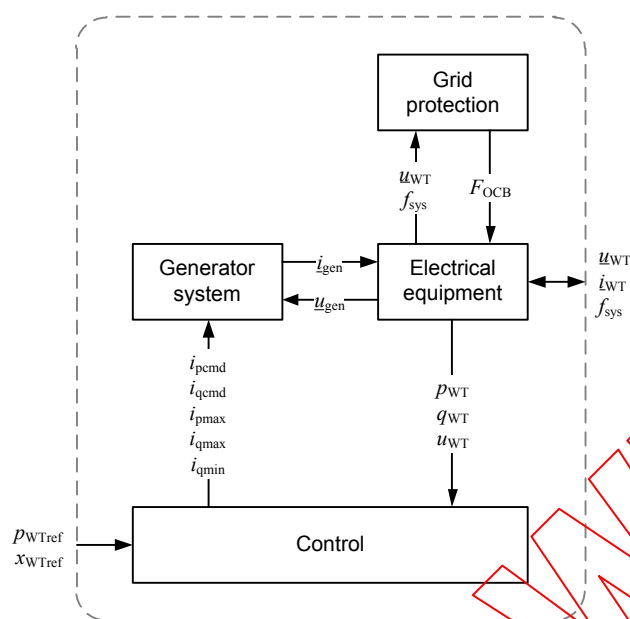


Figure 16 – Modular structure for the type 4A WT model

Figure 17 shows the modular structure for the type 4A control models.

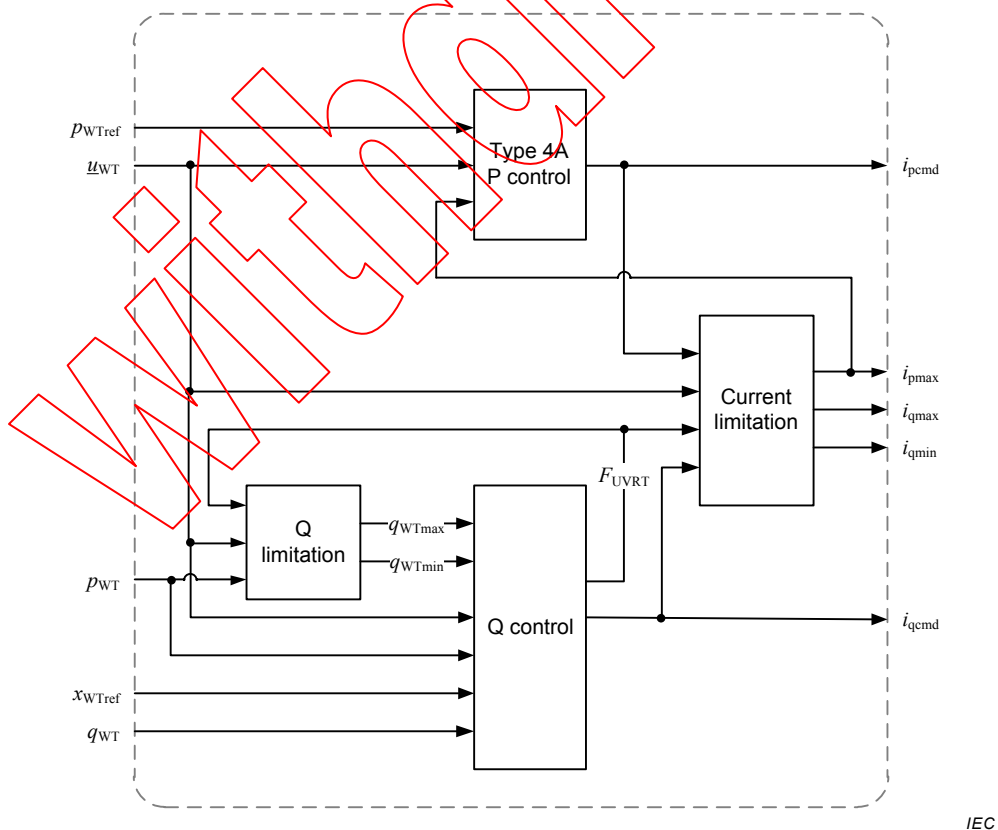


Figure 17 – Modular structure for the type 4A control model

The details for each block are given in the Modules referred to in Table 7.

Table 7 – Modules used in type 4A model

Block	Module clause	Module name
Generator system	5.6.3.4 or 5.6.3.2	"Type 4 generator set model" or "Type 3A generator set model" ^a
Electrical equipment	5.6.4.2 (5.6.4.3)	"Circuit breaker model" ("Transformer model")
Control	5.6.5.5 5.6.5.7 5.6.5.8 5.6.5.9 or 5.6.5.10	"P control model type 4A" "Q control model" "Current limitation model" "Constant Q limitation model" or "QP and QU limitation model"
Grid protection	5.6.6	"Grid protection model"

^a The Type 3A generator set model can be used in type 4 WT models, which will mitigate the reactive power spike appearing when the voltage recovers. This spike is mainly caused by numerical effects in the simulations.

5.5.5.3 Type 4B model specification

The modular structure for the generic type 4B WT model is shown in Figure 18.

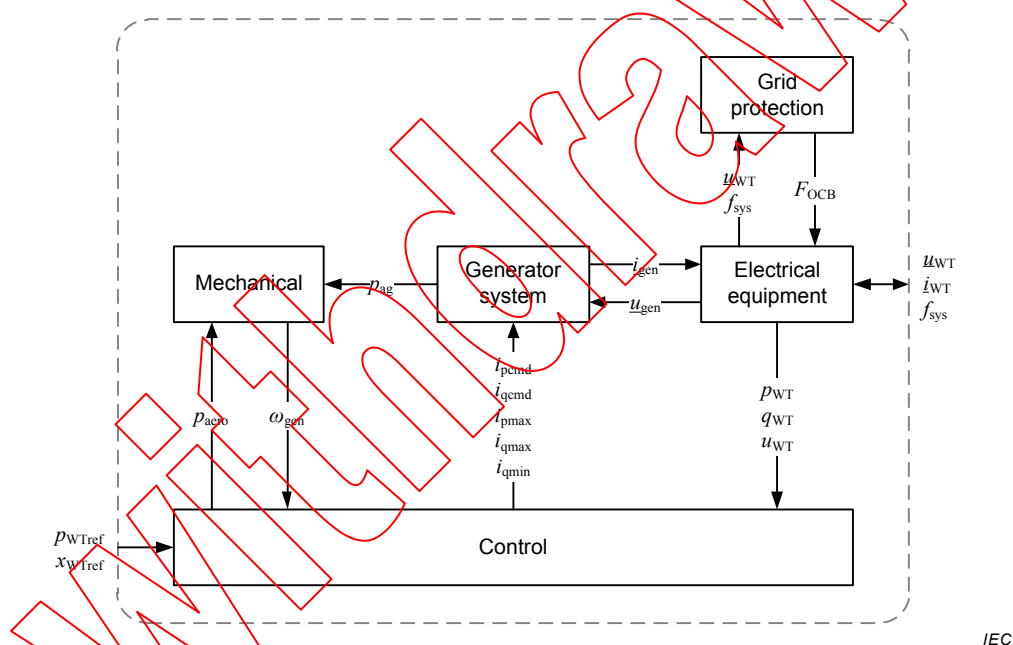
**Figure 18 – Modular structure for the type 4B WT model**

Figure 19 shows the modular structure for the type 4B control models.

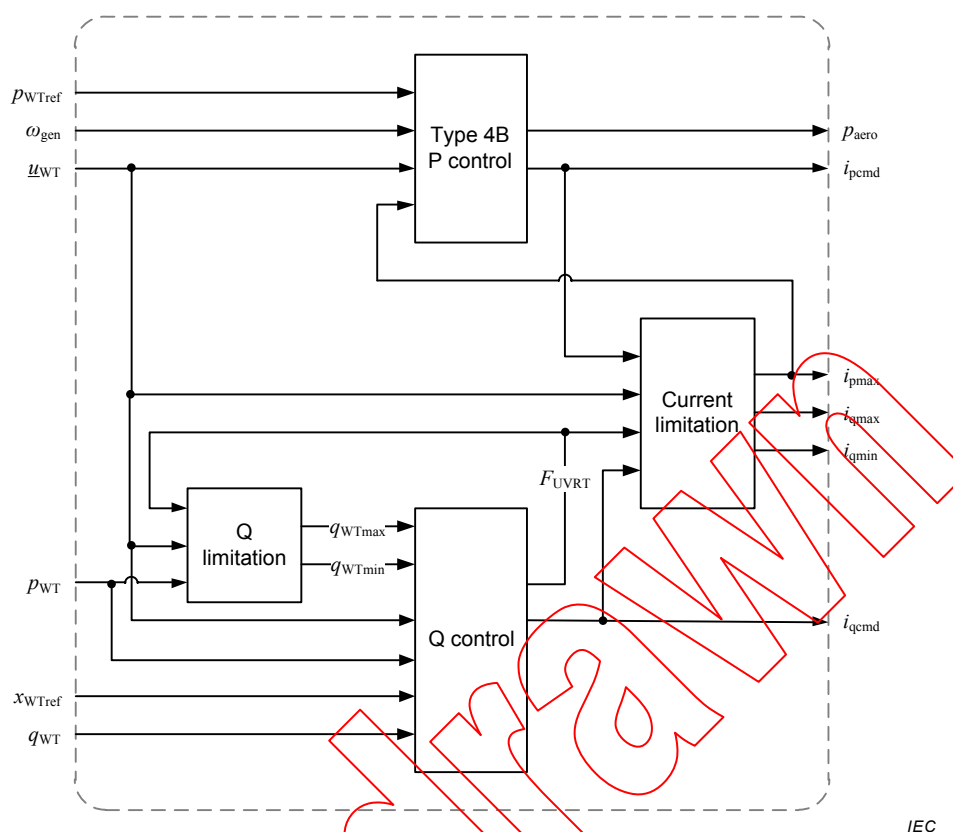


Figure 19 – Modular structure for the type 4B control model

The details for each block are given in the Modules referred to in Table 8.

Table 8 – Modules used in type 4B model

Block	Module clause	Module name
Mechanical	5.6.2.1	"Two mass model"
Generator system	5.6.3.4 or 5.6.3.2	"Type 4 generator set model" or "Type 3A generator set model" ^a
Electrical equipment	5.6.4.2 (5.6.4.3)	"Circuit breaker model" ("Transformer model")
Control	5.6.5.6	"P control model type 4B"
	5.6.5.7	"Q control model"
	5.6.5.8	"Current limitation model"
	5.6.5.9 or 5.6.5.10	"Constant Q limitation model" or "QP and QU limitation model"
Grid protection	5.6.6	"Grid protection model"

^a The Type 3A generator set model can be used in type 4 WT models, which will remove the reactive power spike appearing when the voltage recovers. This spike is mainly caused by numerical effects in the simulations.

5.6 Module library

5.6.1 Aerodynamic models

5.6.1.1 Constant aerodynamic torque model

The block diagram for the constant aerodynamic model is shown in Figure 20. The module requires no manufacturer supplied parameters. The initial torque τ_{init} must be set by the load-flow.

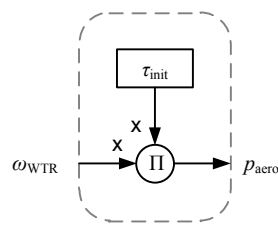


Figure 20 – Block diagram for constant aerodynamic torque model

5.6.1.2 One-dimensional aerodynamic model

This aerodynamic sub model corresponds to the one-dimensional model proposed in Price and Sanchez-Gasca (2006). It includes the dependency on the pitch angle, but neglects the dependency on the rotor speed. The one-dimensional aerodynamic model parameters are given in Table 9, and the block diagram is given in Figure 21. The initial power p_{init} must be set by the load-flow.

Table 9 – Parameter list for one-dimensional aerodynamic model

Symbol	Base unit	Description	Category
Θ_{w0}	deg	Initial pitch angle	Case
k_a	P_n / deg^2	Aerodynamic gain	Type

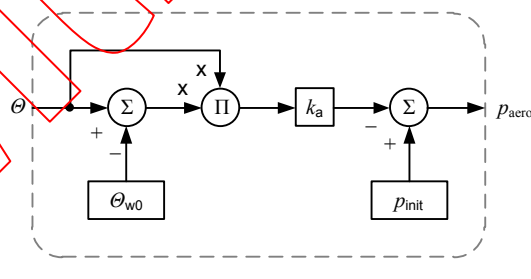


Figure 21 – Block diagram for one-dimensional aerodynamic model

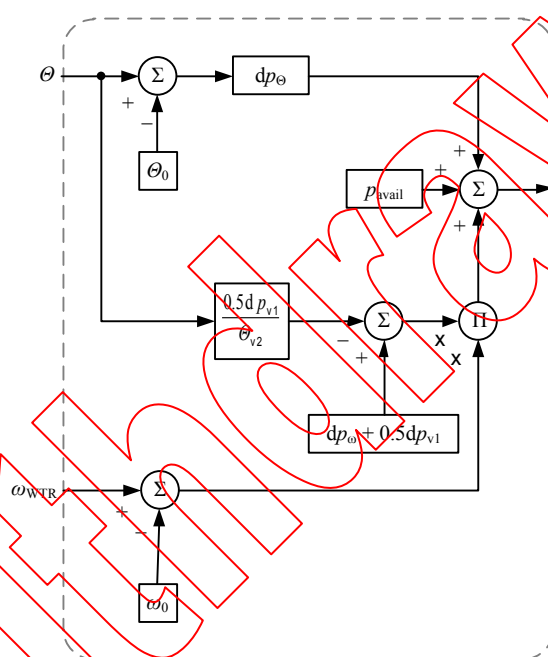
5.6.1.3 Two-dimensional aerodynamic model

The two-dimensional aerodynamic sub model corresponds to the model proposed in Fortmann (2014). The two-dimensional aerodynamic model parameters are given in Table 10, and the block diagram is given in Figure 22.

Table 10 – Parameter list for two-dimensional aerodynamic model

Symbol	Base unit	Description	Category
p_{avail}	P_n	Available aerodynamic power ^a	Case
Θ_0	deg	Pitch angle if the WT is not derated ^b	Case

Symbol	Base unit	Description	Category
ω_0	Ω_{base}	Rotor speed if the WT is not derated	Type
dp_{θ}	P_n / deg	Partial derivative of aerodynamic power with respect to changes in pitch angle	Type
dp_{ω}	$P_n / \Omega_{\text{base}}$	Partial derivative of aerodynamic power with respect to changes in WTR speed	Type
θ_{v2}	deg	Blade angle at twice rated wind speed	Type
dp_{v1}	$P_n / \Omega_{\text{base}}$	partial derivative dp_{ω} at rated wind speed	Type
^a The available aerodynamic power allows modelling derated operation for the integration with wind power plant power controller in order to allow the WT to increase active power if there is enough available aerodynamic power. The initial aerodynamic power cannot be greater than p_{avail}. ^b The pitch angle should normally be zero for $p_{\text{avail}} < 1$ and greater than zero if $p_{\text{avail}} = 1$ or if the initial value of p_{aero} is less than p_{avail}.			



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Figure 22 – Block diagram for two-dimensional aerodynamic model

Annex E describes the background for the two-dimensional aerodynamic model, including a guideline to the WT manufacturer for determination of the case dependent model parameters and for the software vendor how to calculate the initialisation if the necessary parameters are provided by the manufacturer.

5.6.2 Mechanical models

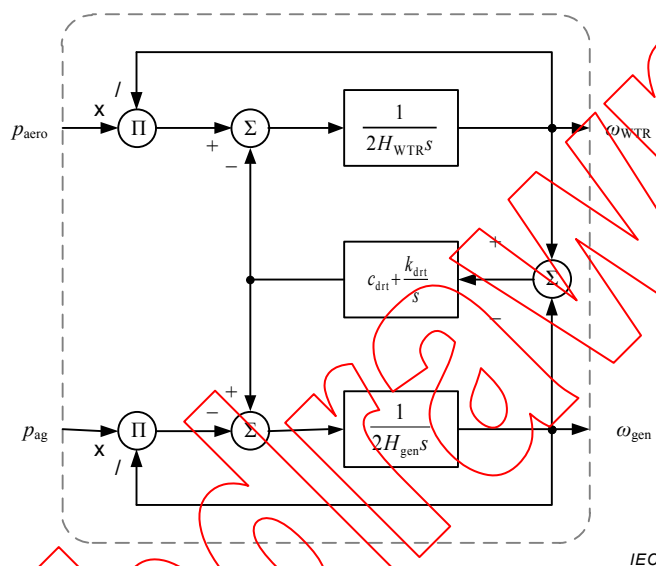
5.6.2.1 Two mass model

The module parameters are given in Table 11, and the block diagram is given in Figure 23.¹³

¹³ Some software tools include the generator inertia in the built-in generator model. In this case, the additional mechanical model should interface with the generator shaft instead of the generator air gap, and consequently not include the generator inertia. The complete mechanical model will then still be a two mass model as described in 5.6.2.1.

Table 11 – Parameter list for two-mass model

Symbol	Base unit	Description	Category
H_{WTR}	s	Inertia constant of WT rotor	Type
H_{gen}	s	Inertia constant of generator	Type
k_{drt}	T_{base}	Drive train stiffness	Type
c_{drt}	$\frac{T_{base}}{\Omega_{base}}$	Drive train damping	Type

**Figure 23 – Block diagram for two mass model**

5.6.3 Generator set models

5.6.3.1 Asynchronous generator model

This standard does not specify a model for the asynchronous generator. The standard asynchronous generator model in the simulation tool should be used. Normal practice for stability studies is to include the rotor flux transients and neglect the stator flux transients.

If motor models are used, then the user must take into account that the modules in this standard assumes generator sign convention.

5.6.3.2 Type 3A generator set model

The module parameters are given in Table 12, and the block diagram is given in Figure 24.

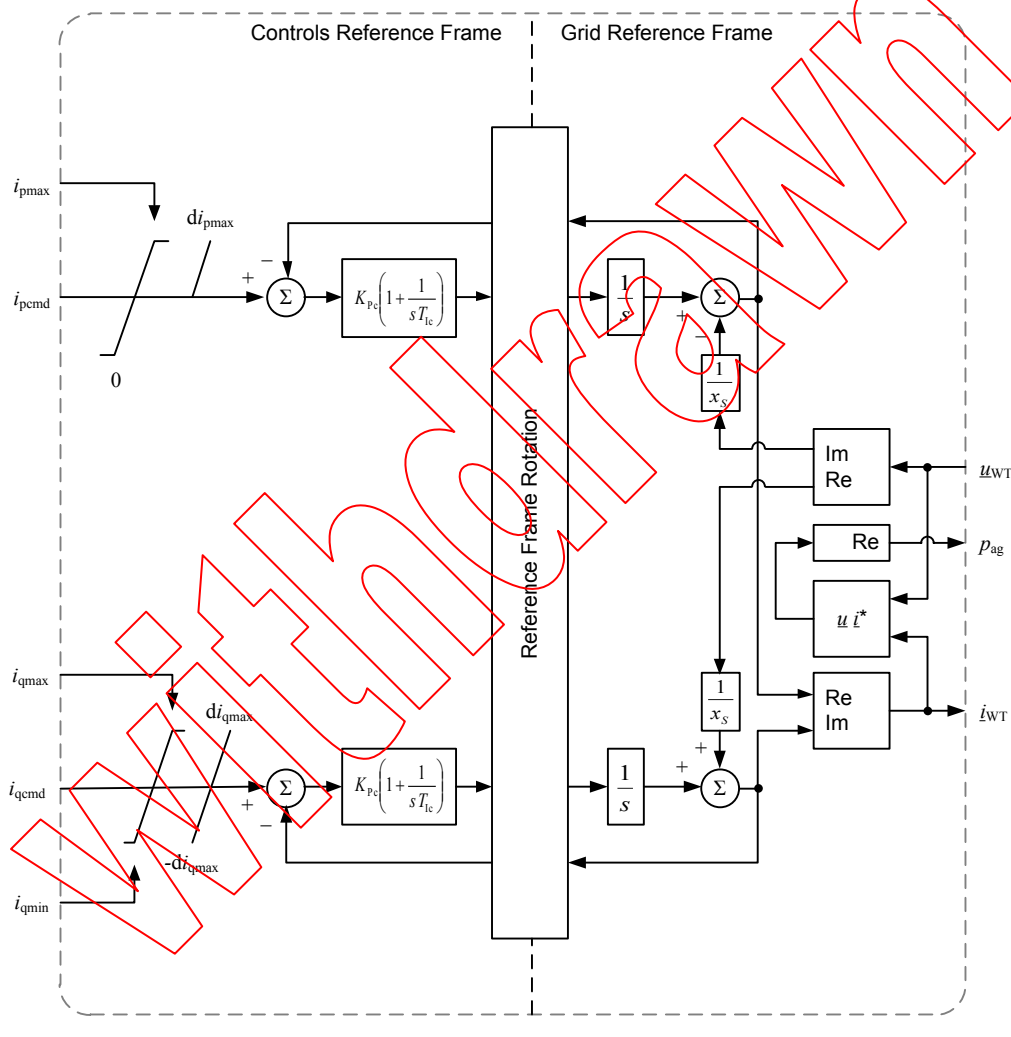
The output of the generator model is a current, injected through a current source with parallel impedance X_s . However, in some power system simulation software, ‘control’-parts and ‘grid’-parts of a model are treated differently. To improve the convergence behaviour of the simulation in such cases, it is recommended to move the parallel impedance X_s described by the term “stator voltage divided by the transient reactance” so that it is incorporated into the grid equations as suggested in Fortmann et al (2014).

The losses in the generator system are neglected setting the generator air gap power p_{ag} equal to the WT terminal power.

Table 12 – Parameter list for type 3A generator set model

Symbol	Base unit	Description	Category
K_{pc}	-	Current PI controller proportional gain	Type
T_{ic}	s	Current PI controller integration time constant	Type
x_s	Z_{base}	Electromagnetic transient reactance ^a	Type
di_{pmax}	I_n/s	Maximum active current ramp rate	Project
di_{qmax}	I_n/s	Maximum reactive current ramp rate	Project

^a The electromagnetic transient reactance should be calculated from the electromagnetic transient inductance as defined in Fortmann et. al. (2014)



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Figure 24 – Block diagram for type 3A generator set model**5.6.3.3 Type 3B generator set model**

The module parameters are given in Table 13, and the block diagram is given in Figure 25. This type 3B generator set model is the state-of-the-art simplification of the 3A generator set model with addition of a crowbar model (Buendia et al, 2012).

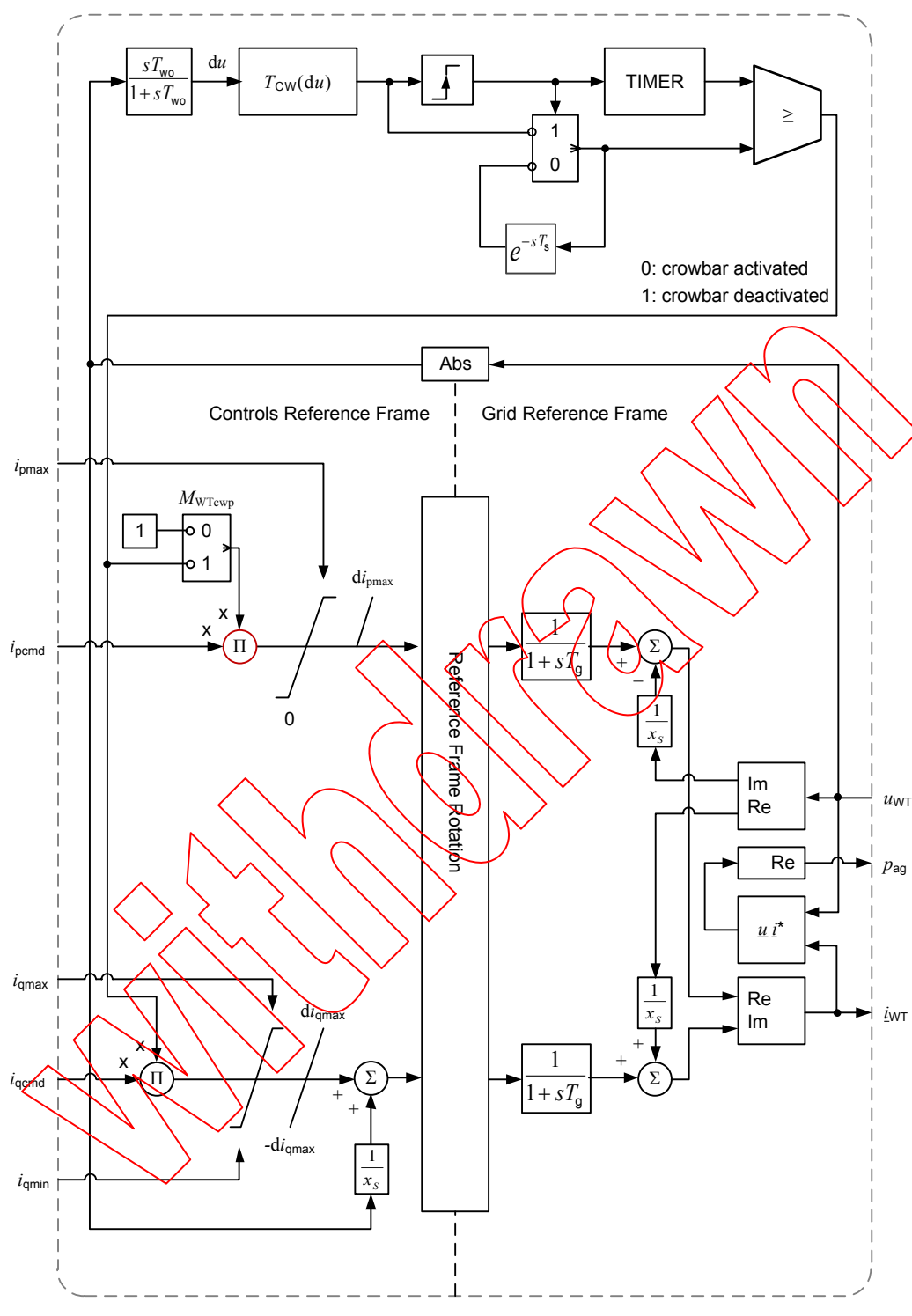
The output of the generator model is a current, injected through a current source. However, in some power system simulation software, the current source needs a parallel impedance to improve the convergence behaviour of the simulation. In such cases, it is recommended to

move the term “stator voltage divided by the transient reactance” so that it is incorporated into the grid equations as suggested in Fortmann et al (2014).

Table 13 – Parameter list for type 3B generator set model

Symbol	Base unit	Description	Category
T_g	s	Current generation Time constant	Type
di_{pmax}	I_n/s	Maximum active current ramp rate	Project
di_{qmax}	I_n/s	Maximum reactive current ramp rate	Project
x_s	Z_{base}	Electromagnetic transient reactance	Type
$T_{CW}(du)$	s vs. U_n	Crowbar duration versus voltage variation look-up table	Case
T_{wo}	s	Time constant for crowbar washout filter	Case
M_{WTcwp}	-	Crowbar control mode	Case

Withdrawing



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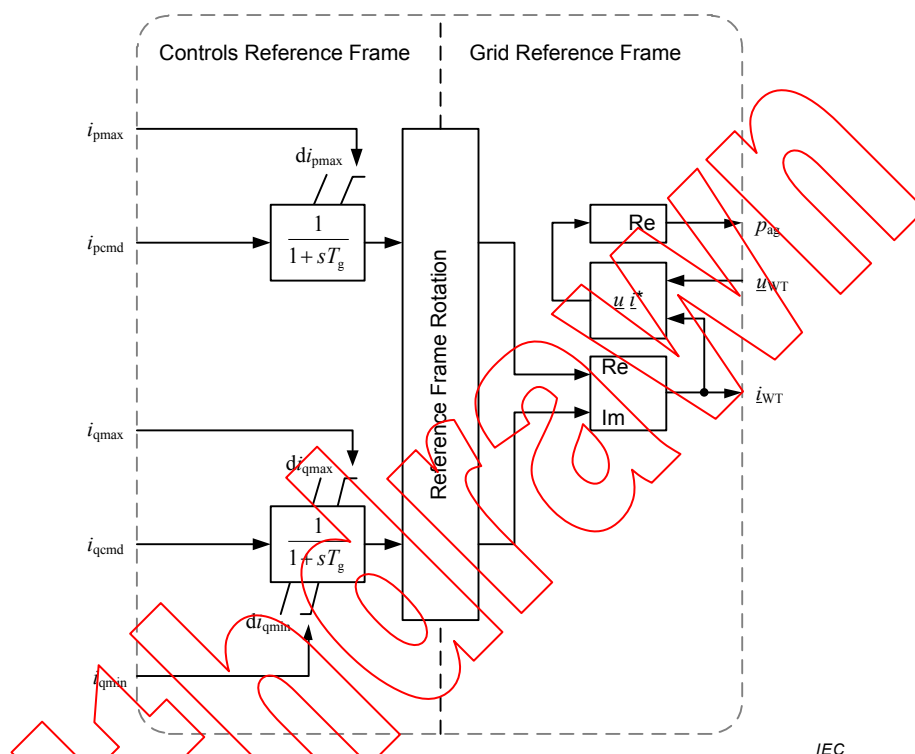
Figure 25 – Block diagram for type 3B generator set model

5.6.3.4 Type 4 generator set model

The module parameters for the type 4 generator model are given in Table 14, and the block diagram is given in Figure 26.

Table 14 – Parameter list for type 4 generator set model

Symbol	Base unit	Description	Category
T_g	s	Time constant	Type
di_{pmax}	I_n/s	Maximum active current ramp rate	Project
di_{qmax}	I_n/s	Maximum reactive current ramp rate	Project
di_{qmin}	I_n/s	Minimum reactive current ramp rate	Project

**Figure 26 – Block diagram for type 4 generator set model**

5.6.3.5 Reference frame rotation model

The module parameters for the reference frame rotation model are given in Table 15, and the block diagram is given in Figure 27.

Table 15 – Parameter list for reference frame rotation model

Symbol	Base unit	Description	Category
T_{PLL}	s	Time constant for PLL first order filter model	Type
u_{PLL1}	U_n	Voltage below which the angle of the voltage is filtered and possibly also frozen ^a	Type
u_{PLL2}	U_n	Voltage below which the angle of the voltage is frozen if $u_{PLL2} \leq u_{PLL1}$ ^b	Type

^a Angle is filtered and/or frozen to avoid instabilities due to lack of voltage reference.

^b The value of u_{PLL2} should be coordinated with the value of u_{PLL1} . Usually, $u_{PLL2} \leq u_{PLL1}$. u_{PLL2} is employed to avoid numerical problems when voltage is close to zero and then angle is not numerically valid.



Figure 27 – Block diagram for the reference frame rotation model

5.6.4.1 Shunt capacitor models

5.6.4.2 ~~Circuit breaker model~~

5.6.4.3 Transformer model

5.6.5 Control models

5.6.5.1 Pitch control power model

This module corresponds to the type 1 and type 2 WT pitch controller proposed for the 2nd generation WECC models (Pourbeik 2013). The module parameters are given in Table 16, and the block diagram is given in Figure 28.

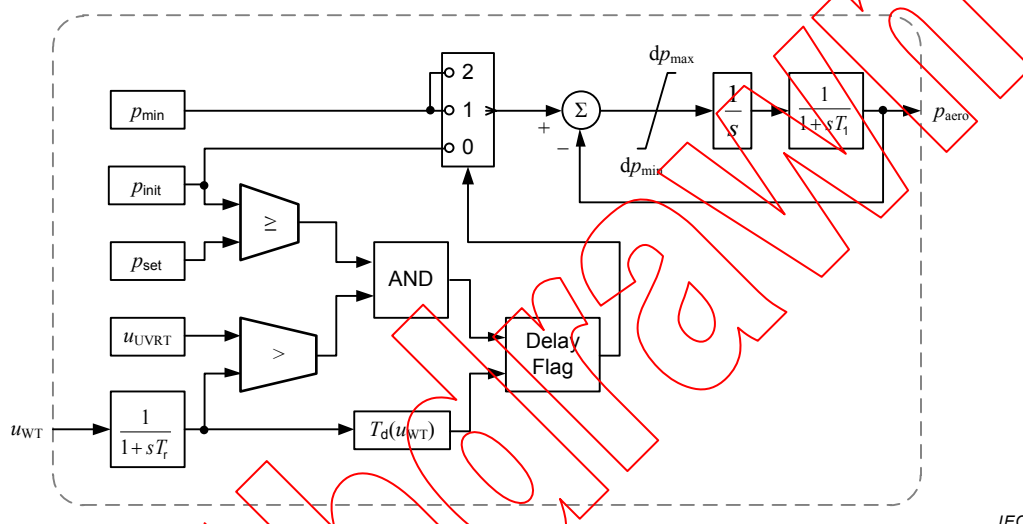
Table 16 – Parameter list for pitch control power model

Symbol	Base unit	Description	Category
T_r	s	Voltage measurement time constant	Type
$dp_{\max}$	P_n	Rate limit for increasing power	Type
$dp_{\min}$	P_n	Rate limit for decreasing power	Type

Symbol	Base unit	Description	Category
T_1	s	Lag time constant	Type
$p_{\min}$	P_n	Minimum power setting	Type
p_{set}	P_n	If $p_{\text{init}} < p_{\text{set}}$ then power will be ramped down to $p_{\min}$	Type
$T_d(u_{\text{WT}})$	$s(U_n)$	Lookup table to determine the duration of the power reduction after a voltage dip, depending on the size of the voltage dip ^a	Type
u_{VRT}	U_n	Dip detection threshold ^b	Type

^a Note that for compatibility with the WECC models, the lookup table must be defined as steps between four points.

^b Note that for compatibility with the WECC models, u_{VRT} must be equal to the highest voltage in $T_d(u_{\text{WT}})$.



NOTE The initial power p_{init} is set by the load flow.

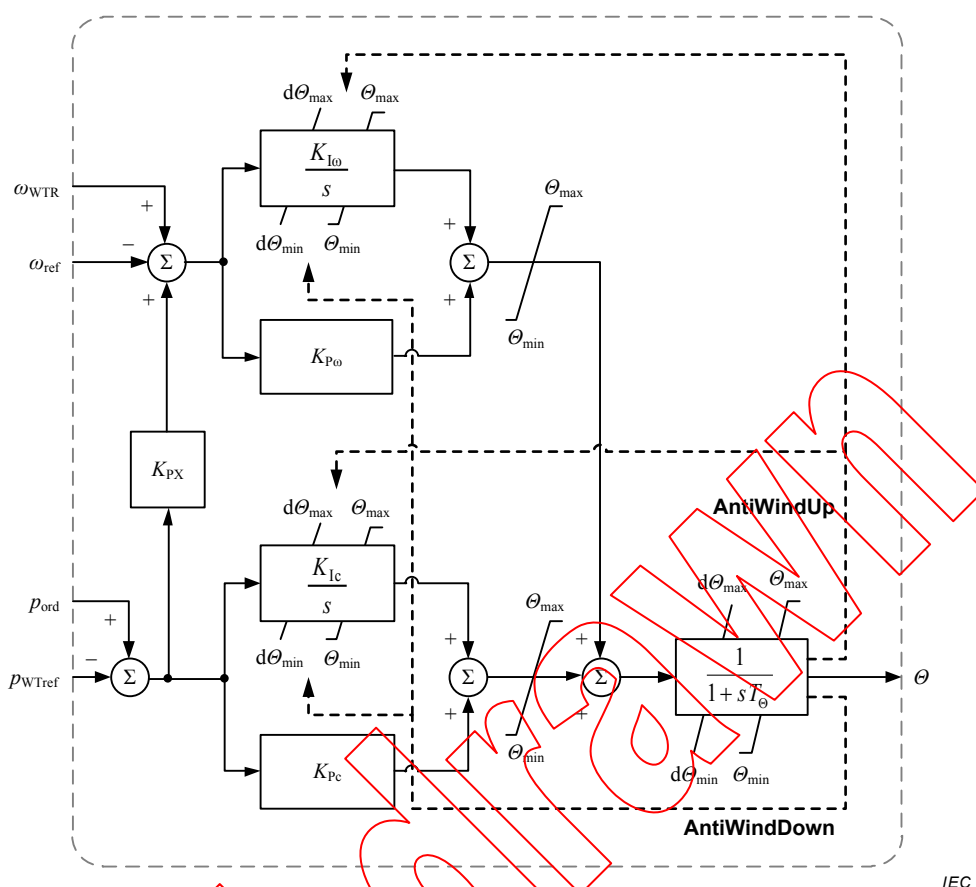
Figure 28 – Block diagram for pitch control power model

5.6.5.2 Pitch angle control model

The module parameters are given in Table 17, and the block diagram is given in Figure 29.

Table 17 – Parameter list for pitch angle control model

Symbol	Base unit	Description	Category
$K_{P\omega}$	$\text{deg}/\Omega_{\text{base}}$	Speed PI controller proportional gain	Type
$K_{I\omega}$	$\text{deg}/\Omega_{\text{base}}/\text{s}$	Speed PI controller integration gain	Type
K_{Pc}	deg/P_n	Power PI controller proportional gain	Type
K_{Ic}	$\text{deg}/P_n/\text{s}$	Power PI controller integration gain	Type
K_{PX}	Ω_{base}/P_n	Pitch cross coupling gain	Type
$\Theta_{\max}$	deg	Maximum pitch angle	Type
$\Theta_{\min}$	deg	Minimum pitch angle	Type
$d\Theta_{\max}$	deg/s	Maximum pitch positive ramp rate	Type
$d\Theta_{\min}$	deg/s	Maximum pitch negative ramp rate	Type
T_{Θ}	s	Pitch time constant	Type



NOTE The block diagram uses the anti windup integrator described in Annex G.8 and the first order filter with limitation detection described in Annex G.10.

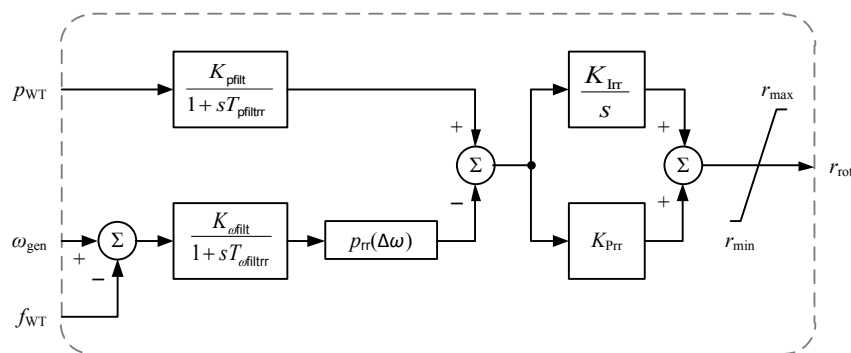
Figure 29 – Block diagram for pitch angle control model

5.6.5.3 Rotor resistance control model

The module parameters are given in Table 18, and the block diagram is given in Figure 30.

Table 18 – Parameter list for rotor resistance control model

Symbol	Base unit	Description	Category
$T_{pfiltrr}$	s	Filter time constant for power measurement	Type
K_{pfilt}	-	Filter gain for power measurement	Type
$T_{\omega filtrr}$	s	Filter time constant for generator speed measurement	Type
$K_{\omega filtr}$	-	Filter gain for generator speed measurement	Type
$p_r(\Delta\omega)$	$\frac{P_n}{(\Omega_{base})}$	Power versus speed change (negative slip) lookup table	Type
K_{Prr}	$\frac{Z_{base}}{P_n}$	Proportional gain in rotor resistance PI controller	Type
K_{Irr}	$\frac{Z_{base}}{P_n/s}$	Integral gain in rotor resistance PI controller	Type
r_{max}	Z_{base}	Maximum rotor resistance	Type
r_{min}	Z_{base}	Minimum rotor resistance	Type



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NOTE The original IEEE / WECC model uses motor sign convention for power and slip in accordance with text book models for asynchronous machines. This standard uses generator sign convention, and therefore the PI controller input sign is reversed compared to the signs in the original IEEE / WECC model.

Figure 30 – Block diagram for rotor resistance control model

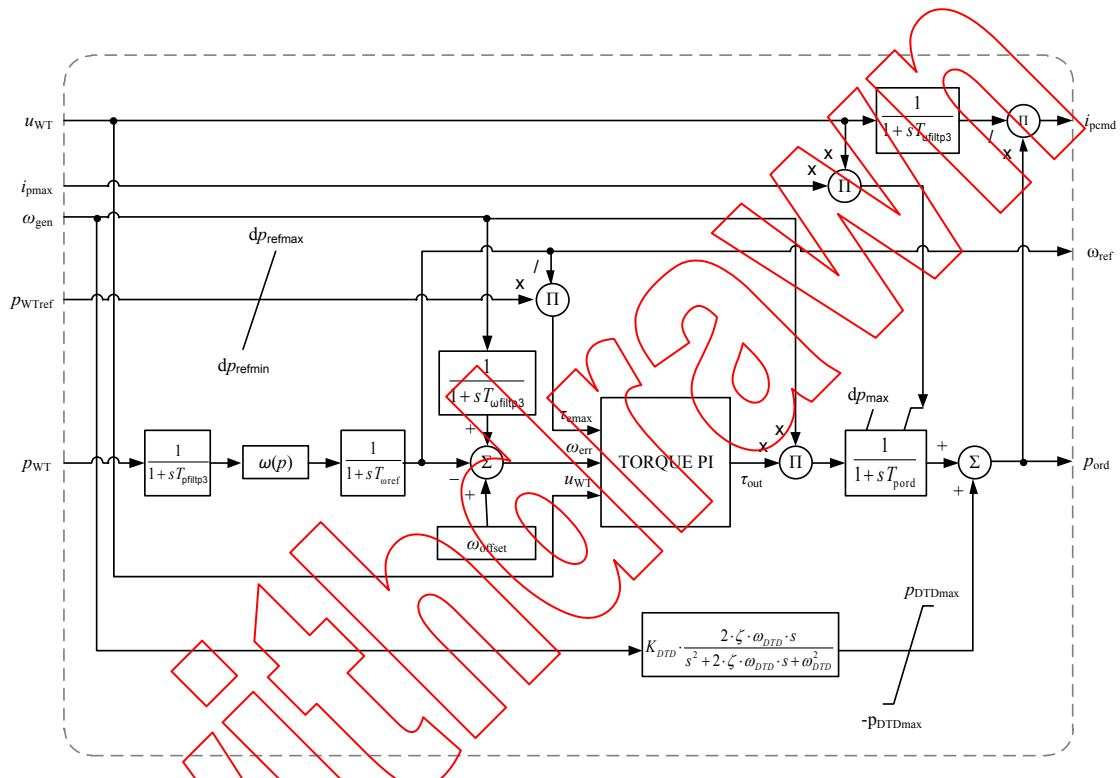
5.6.5.4 P control model type 3

The module parameters are given in Table 19, and the block diagrams are given in Figure 31 and Figure 32.

Table 19 – Parameter list for p-control model type 3

Symbol	Base unit	Description	Category
ω_{offset}	Ω_{base}	Offset to reference value that limits controller action during rotor speed changes	Case
$\omega(p)$	$\Omega_{\text{base}} (P_n)$	Power vs. speed lookup table	Type
K_{Pp}	$T_{\text{base}} / \Omega_{\text{base}}$	PI controller proportional gain	Type
K_{Ip}	$T_{\text{base}} / \Omega_{\text{base}} / s$	PI controller integration parameter	Type
T_{pfiltp3}	s	Filter time constant for power measurement	Type
T_{ufiltp3}	s	Filter time constant for voltage measurement	Type
$T_{\omega\text{ref}}$	s	Time constant in speed reference filter	Type
$T_{\omega\text{filtp3}}$	s	Filter time constant for generator speed measurement	Type
K_{DTD}	$P_n / \Omega_{\text{base}}$	Gain for active drive train damping	Type
P_{DTDmax}	P_n	Maximum active drive train damping power	Type
ζ	-	Coefficient for active drive train damping	Type
ω_{DTD}	Ω_{base}	Active drive train damping frequency, can be calculated from two mass model parameters in Table 11: $\omega_{\text{DTD}} = \sqrt{k_{\text{drt}} \cdot \left(\frac{1}{2 \cdot H_{\text{WTR}}} + \frac{1}{2 \cdot H_{\text{gen}}} \right)}$	Type
T_{pord}	s	Time constant in power order lag	Type
dp_{max}	P_n / s	Maximum WT power ramp rate	Type
dp_{refmax}	P_n / s	Maximum ramp rate of WT reference power	Project
dp_{refmin}	P_n / s	Minimum ramp rate of WT reference power	Project
u_{pdip}	U_n	Voltage dip threshold for P-control. Part of turbine control, often different (e.g 0.8) from converter thresholds.	Project
$d\tau_{\text{max}}$	T_{base} / s	Ramp limitation of torque, required in some grid codes	Project

Symbol	Base unit	Description	Category
τ_{emin}	T_{base}	Minimum electrical generator torque	Type
τ_{uscale}	T_{base}/U_n	Voltage scaling factor of reset-torque	Project
M_{pUVRT}	-	Enable UVRT power control mode (0: reactive power control – 1: voltage control)	Project
$d\tau_{maxUVRT}$	T_{base}/s	Limitation of torque rise rate during UVRT	Project
u_{DVS}	U_n	Voltage limit for hold UVRT status after deep voltage sags	Project
T_{DVS}	s	Time delay after deep voltage sags	Project



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NOTE The TORQUE PI block is detailed in Figure 32.

Figure 31 – Block diagram for type 3 P control model