Offshore Grid Connection Requirements

Annex A_04: Requirements for RMS simulation model

Area of application: DC-connected Offshore Windfarms

Revision history

Rev. Number	Date	Change	Author
1.0	28.07.2025	First edition	E. Wiebe (AMP) T. Nguyen (50HzT)

1 General

This document provides supplementary requirements to [1] and [2]. This annex describes the requirements from the TSO for the RMS simulation model of DC-connected Offshore Windfarm (OWF).

2 Standards

If no explicit standards are specified, the following systems of standards shall be followed in the prioritized order:

i. German standards and regulations, including the grid codes of TSO
ii. Cenelec
iii. IEC
iv. Cigré recommendations
v. IEEE standards and recommendations.

If alternative standards will be used, they shall be approved by TSO. The latest edition including amendments of each standard and regulation shall apply.

SI units and the passive sign convention shall be used in all documents, if it is not otherwise specified by the TSO.

3 References

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs:

[1] VDE-AR-N 4131: 2019-03: Technische Anschlussbedingungen für HGÜ-Systeme und über HGÜ-Systeme angeschlossene Erzeugungsanlagen (TAR HGÜ)
[2] 50HzT, AMP: Offshore-Netzanschlussregeln
[3] 50HzT, AMP: Offshore Grid Connection Requirements, Annex A_01 General Requirements for Compliance Studies and Models
[4] 50HzT, AMP: Offshore Grid Connection Requirements, Annex A_02 Main Circuit Parameter Report

4 Definitions

TSO	Transmission System Operator
HVDC	High Voltage Direct Current
HIL	Hardware in the Loop

DLL	Dynamic Link Library
HMI	Human-Machine Interface
OWF	Offshore Windfarm
WTG	Wind Turbine Generator
RMS	Root Mean Square
PLL	Phase-Locked Loop
FSM	Frequency Sensitive Mode
LFSM	Low Frequency Sensitive Mode
EPC	Emergency Power Control

5 Model deliverables

The connectee shall develop and provide to TSO detailed RMS models of the Offshore OWF incl. the Wind Turbine Generators (WTGs) and model of the windfarm controller in the software DIgSILENT PowerFactory.

The connectee shall provide the preliminary model to the TSO and the HVDC manufacturer in an early stage of the project in order to allow the HVDC manufacturer to design and optimize the control.

The model shall be implemented directly within DIgSILENT PowerFactory (by means of DSL code or the graphic interconnection of DSL macros) without using external, pre-compiled components (e.g., DLL files). If it is necessary to use encryption or pre-compiled components, the Contractor shall supply two models:

1. An open, unencrypted RMS model, completely implemented in DIgSILENT PowerFactory (by means of DSL code or the graphic interconnection of DSL macros), which may involve simplified modelling for selected parts of the control system to protect intellectual property. Model inaccuracies caused by such simplifications shall be described, documented, and evaluated during validation. However, general conformity with the simulation results from the model and the measured system behaviour shall be achieved.
2. A detailed RMS model that depicts the control system and system behaviour as accurately as possible. This model may be implemented using external, pre-compiled components (e.g., DLL files) or encrypted DSL code.

The connectee can provide windfarm controller model either with open control blocks or encrypted controls with original controller code or in DLL format. However, the model documentation shall include the control block diagrams fully describing the controllers incl. parameter set.

The connectee shall provide the model as used in the compliance studies together with study report to the TSO, including models of the DC-connected OWF and the AC network representation, if applicable. The connectee shall hand-over a RMS model which include exclusively relevant study cases from the compliance study.

The model shall be provided as a runnable file combined with the project specific HVDC model (which is provided by the TSO) and with a Thevenin Source.

The model shall be provided with a detailed documentation. Chosen model parameters shall be documented with explanations.

The connectee shall validate the model and provide a validation report.

6 Model requirements

The connectee shall deliver the RMS model in a DIgSILENT PowerFactory version defined by TSO. The model shall run on 64- and 32-bit systems. The simulation time steps shall be adjustable within the range of 1 ms to 20 ms. The model shall be able to run with automatic step size adaptation.

The model shall be valid in millisecond range for all defined operation points and operation modes according in the positive-sequence, negative-sequence and zero-sequence systems. Different parameters such as set-points and ramps shall be adjustable by the user. Tap changer control for automatic determination of the optimal tap position in load flow as well as during dynamic simulations shall be included in the model, if applicable.

The model shall automatically initialise for all operation points within all operation modes. Based on the load flow results, the model shall start with a flat run in the dynamic calculation not triggering any transients in the AC network model. Deviations from the initialized values at the start of the simulation shall be avoided, along with error and warning messages in the message window of the simulation software. Information messages shall be kept to a minimum and shall be properly documented.

The model shall include all data relevant to allow the TSO performing steady-state load flow and short-circuit calculations alongside the RMS simulation functionality. These include the reactive power capacity, short-circuit power or current contribution, the X/R ratio in the positive-phase sequence system, and zero-phase sequence system impedances.

The model shall realistically represent the OWF’s behavior in all power system stability aspects, including voltage stability, frequency stability, rotor angle stability and new converter-driven stability aspects.

The model shall contain all primary equipment (e.g. transformers, chopper, filters,

compensation devices, neutral-point impedances, generator, converters, cables etc.). The model shall contain frequency dependent models for all relevant components (e.g., cables, transformers).

The model shall include a representation of wind turbine aerodynamic and mechanic system. On the aerodynamic side, the model shall consider the reactions of the wind turbine with effect on energy conversion (e.g. speed change). The model shall represent the mechanical dynamics (such as inertial response from the wind turbine), which have an influence on the electrical behaviour.

The model shall realistically represent the measurement system's and control system's effect (e.g. time delay). The model shall properly depict the control systems that influence the behaviour of the converter in the relevant time range for RMS simulations.

A simplification of the synchronisation mechanism of the converter (PLL) shall be justified and documented, if applicable. The model shall consider all design limits. The model shall include all required functions according to to [1] and [2] which are active in the specified time range.

The connectee shall include all protection functions. Delays caused for example by signal processing shall be represented. If a protective function leads to a trip or blocking, the model needs to show which protection functions are triggered.

The model shall include all faults which are necessary to perform the system conformity study. The faults shall be adjustable by TSO.

For supplementary stability functions, i.e. AC voltage control, active and reactive power control, LFSM-O/U, FSM and EPC activation (if applicable), the settings and parameters shall be accessible and adjustable respectively for TSO. Primary equipment shall not be encoded. If parts of the control are encoded, the following signals, settings and parameters shall be accessible and adjustable respectively for TSO:

- Dynamic active current limitation
- Dynamic reactive current limitation
- All required functions and control modes
- Set-points of all required functions and control modes
- Parameters of all required functions and control modes where different parameters shall be changeable to simulate the different behavior of the DC-connected OWF.

The model shall include a graphical user interface, e.g. with buttons, sliders and switches for adjusting different switching configurations, set-points and controls modes for the model of all OWF and WTGs:

- Selection of all control modes according to grid code,
- Set-points of all relevant control modes,
- Wind speed and or active power set point,
- State of all circuit breakers.

7 Validation

The encrypted detailed vendor RMS model (Section 5 Bulletpoint 2) of the wind turbine generator and of the park controller shall be validated by using one of the following methods:

- Certificated measurements,
- Validated EMT model,
- Factory test results (real-time simulations with the actual control system implementation).

The connectee shall use at least the following benchmark scenarios to validate the RMS model:

- AC faults (symmetrical and unsymmetrical),
- Step response tests of relevant control functions,
- Functional tests of relevant control functions (e.g. AC voltage control, active and reactive power control, LFSM-O/U, FSM, EPC activation (if applicable),
- Network disconnection (island operation after disconnection from the network connection system or blocking of the HVDC system),
- Selected cases for grid forming control, to be aligned with TSO.

The connectee shall consider all of the following boundary conditions to validate the RMS model:

- Different loads and operation points,
- Different control modes,
- Different control parameters of the relevant control functions.

The connectee shall apply a maximum of 5 % (of the nominal values) margin of deviation in the electrical quantities (voltage, current etc.) as the steady-state validation criterion. The connectee shall provide a technical explanation for the cases that exceed a 10 % deviation margin as transient validation criterion.

The connectee may use HIL (hardware in the loop) testing to validate the WTG-level and OWF-controller. The connectee shall apply a maximum of 3% (of the respective maximum values) margin of deviation as the validation criterion.

The connectee shall verify the simulation results of the offshore windfarm model by measurements taken during the grid code compliance tests.

The test cases shall be further developed jointly by the connectee and TSO and shall be approved by TSO.

8 Documentation

The connectee shall document the models in detail following the general requirement stated in [3].

The model documentation shall include all equipment data and operating data of the OWF and WTGs as required in [1] and [4].

The model documentation shall include a suitable description of the model:

- The documentation shall include a single line diagram indicating the in- and output parameters and variables.
- The names and units of in- and output parameters and variables shall be described in detail.
- The HMI of the model, meaning the parameters adjustable by the user shall be highlighted in the model and clearly described in terms of unit, parameter range, default values etc.
- Other main parameters of the model, which are not adjustable but relevant for the user, like nominal power, point of connection, etc. shall be given in the model.
- The control scheme shall be described by block diagrams.
- Any limits in terms of operational ranges, time steps etc. shall be described.
- A guideline how to integrate the model in other simulation projects (e.g. HVDC model) in the specific software shall be part of the report.
- A description how to operate the model shall be added to the report.

The connectee shall provide and update the documentation of the validation together with every model delivery. The validation report shall include parameters and set values of all required functions and control modes according to [1] and [2]. The connectee shall highlight the changed sections in updated validation reports.