Offshore Grid Connection Requirements

Annex A_05:

Requirements for EMT simulation model

Area of application: DC-connected Offshore Windfarms

Revision history

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

1 General

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

The models shall enable the TSO to perform own system studies for the entire lifetime of the customer installation.

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_07 Dynamic Performance Study

[5] 50HzT, AMP: Offshore Grid Connection Requirements, Annex A_09 Grid Forming Control

Study

[6] 4 TSO Position paper: REQUIREMENTS REGARDING THE PROVISION OF EMT SIMULATION MODELS - Harmonised EMT model requirements for HVDC and STATCOM 4 TSO Position Paper

4 Definitions

OWF	Offshore Windfarm
WTG	Wind Turbine Generator
DBS	Dynamic Braking System
DLL	Dynamic Link Library
EMT	Electromagnetic Transients
EPC	Emergency Power Control
GCP	Grid Connection Point

5 Model deliverables

The connectee shall develop and provide EMT models of DC-connected WTG and OWF to the TSO. The connectee shall consider all requirements of sections 6, 7 and 8 in [3]. The connectee shall validate the model as specified in Section 6 and 7. The connectee shall document the model as specified in Section 6,7 and 8.

6 Model requirements

6.1 Tool-Independent Model Requirement

As a rule, the provision of data (e.g. equivalent circuit diagrams, parameters for the power component, information on the control system) and the control software provided in the form of compiled libraries, including the associated documentation of the interfaces, must enable the TSO to independently implement a model of the OWF and WTG in any simulation software using different software interfaces.

The data and model provision for the simulation of the OWF and WTG shall be tool-independent.

The connectee shall use the document “Requirements regarding the provision of EMT Simulation models” [6] as basis and technical guideline for the tool-independent model development. Despite the document is intended for HVDC and Statcom applications, it shall be applied for offshore wind applications as a converter-based system. In case of discrepancies and uncertainties the OWF shall inform the TSO and the TSO shall decide about requirement applicability.

6.2 Tool-Dependent Model Requirement

The connectee shall deliver the EMT model in PSCAD with a software version, including the versions of Fortran Compiler and Visual Studio, as defined by TSO.

The tool-dependent model shall be developed in accordance with the chapter 2.3 of the document “Requirements regarding the provision of EMT Simulation models” [6]. Deviations from these requirements may be permitted only with approval and specification by the TSO.

The model shall run on 64 and 32 bit systems. The model shall be valid in a frequency range between 0 Hz and 9000 Hz.

The model shall run with a variable time step in the range of µs. If it is not possible to run the model with a variable time step, the model shall be able to run with time steps of 1 µs, 5 µs,

10 µs and 20 µs.

The model shall be valid for all operation points and operation modes in the positive-sequence, negative-sequence and zero-sequence systems. Different parameters such as set-points, ramps, or relevant controller settings shall be adjustable by the user. Tap changer control shall be included in the model, if applicable.

The model shall be capable of performing the system studies requested by the grid code compliance process, i.e. dynamic study, grid forming control study, as defined in [4] and [5]. The model shall be capable of calculating the frequency dependent output impedance of the WTG and OWF at the GCP.

The model shall automatically initialise for all operation points and within all operation modes and reach steady state operating point not later than 5 seconds of simulation time. The initialization shall be coordinated with the project-specific HVDC model.

The model shall be capable of specifying a point of time from which on the OWF and WTG synchronise with the network and may supply power. The model shall support the snapshot and multiple run function. The model shall include a representation of the real control and measurement system, including signal and communication processing which is relevant for the specified frequency range.

The model shall include a representation of wind turbine aerodynamic and mechanical 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.

There shall be a reference in the model to the software version(s) embedded in the WTG and WTG hardware installed onsite that the model corresponds to. The model shall consider all design limits.

The model shall include the original source code of the controller of all required functions which are active in the specified frequency range for this model.

The model shall contain the primary equipment of the WTG and the OWF (e.g. transformers incl. saturation characteristics, DBS (if applicable), filters, compensation devices, neutral-point impedances, converter, cables, etc.). The model shall contain frequency dependent characteristics of all cables, transformers and other equipment. The OWF model shall include at least one string with largest cable length and one string with the shortest cable length in full details per GCP including all WTGs and WTG-transformers, inter-array cables. The rest of the OWF inter array cable grid may be reduced.

The model shall contain protection functions incl. nonlinearities of instrument transformers and

time delays caused by e.g. signal processing. All protection functions that may potentially lead to tripping or (temporary) blocking of WTG and OWF after an event in the connected AC networks (including submodule level protective actions) shall be included.

With the model for protection functions, the connectee shall ensure, that TSO can reliably assess whether WTG and OWF trips or (temporarily) blocks in case of any event in the connected AC system.

The protection functions including their triggering values shall be described in the model documentation. All protection functions shall be observable in the model, providing the information why and when the OWF and WTG has tripped or (temporarily) blocked. The connectee shall test all protection functions in an adequate manner and describe them as part of the documentation.

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

If the model contains encrypted parts due to intellectual property reasons only the control code may be encrypted and the following requirements shall be fulfilled:

- A signal-flow-diagram of the encrypted parts shall be provided.
- OWF-level control block shall not be encrypted.
- Alternatively, if for practical reasons, the OWF-level controls are encrypted, control block diagrams fully describing the controllers including parameter set shall be provided to the TSO.
- The OWF-level controls shall be provided with original controller code or in DLL format according to [6].

For supplementary stability functions, i.e. AC voltage control, active and reactive power control, LFSM-O/U, FSM and EPC function (if applicable), the settings and parameters shall be accessible and adjustable respectively for TSO.

If parts or the control are encrypted, the following signals, settings and parameters shall be accessible and adjustable respectively for TSO:

- Dynamic active current limitation,
- Dynamic reactive current limitation,
- Status, if the protection system is activate or deactivate and information which protection system (including protective actions on OWF hardware level) is triggered,
- Signals which are used to trigger protection systems,
- All reference signals which are relevant for the control systems,
- Measured and filtered voltage and current signal before it is used in the control,
- Measured frequency used for dq transformation,
- Output signals of required functions and control modes according to the grid code,
- Set-points of all required functions and control modes according to the grid code,
- Parameters of all required functions and control modes according to the grid code,
- Activation / deactivation of the DBS (if applicable),
- DBS state (energy/thermal performance), if applicable,
- All relevant variables required for compliance with the grid code.

In the model at least the following signals shall be accessible for the user:

- AC voltage (magnitude and phase angle) and frequency at GCP of all OWFs and at the grid side of the transformer of all WTG
- Active and reactive power of the converters at GCP for all OWFs and at the grid side of the transformer of all WTG
- DC voltage and energy stored in the converters.
- Active and reactive currents in the positive, negative and zero sequence at both sides of the WTG transformer, respective GCPs if applicable
- Positive, negative and zero sequence voltages at both sides of the WTG transformer, respective GCPs, if applicable
- Phase angle for the positive sequence voltages at both sides of the WTG transformer, respective GCPs, if applicable

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 different control modes,
- Wind speed and or active power set point,
- factor for the scaling of the WTGs,
- State of all circuit breakers

7 Validation

The EMT model of the wind turbine generator and of the park controller shall be validated by using one of the following methods:

- Certificated measurements
- 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 final EMT models:

- 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 EMT 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.

If the tool-dependent model is not developed in accordance with the chapter 2.3 of the document “Requirements regarding the provision of EMT Simulation models” [6], the tool-indepedant and the tool-dependant EMT model shall be validated separately.

8 Documentation

The connectee shall document the models in line with general requirements on documentation as defined in [1].

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 of 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 the VDE-AR-N-4131 and TSO's Offshore Grid Connection Requirement. The connectee shall highlight the changed sections in updated validation reports.