

TECHNICAL SPECIFICATION

**Grid code compliance assessment methods for grid connection of renewable
energy power plants**

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Grid code compliance assessment methods for grid connection of renewable energy power plants

FOREWORD

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IEC TS 63102 has been prepared by subcommittee 8A: Grid Integration of Renewable Energy Generation, of IEC technical committee 8: System Aspects of Electrical Energy Supply. It is a Technical Specification.

This second edition cancels and replaces the first edition published in 2021. This edition constitutes a technical revision.

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

- a) in terms of scope, wind and PV power plants are replaced by the renewable energy power plants that includes wind power plants, PV power plants and hybrid power plants. Oscillation and grid adaptability are added in the assessment scope;
- b) Clause 5 optimizes the descriptions of compliance field testing, compliance simulation, HIL simulation and compliance monitoring assessment methods, and recommends corresponding assessment methods according to different phases of renewable energy power plants and various assessment items;

- c) Clause 6 supplements compliance field test methods for reactive power capability assessment;
- d) Clause 7 adds synthetic inertia response and voltage slope control to control performance assessment, adjusts recommended contents for field testing and HIL simulation, improves applicable conditions and reference procedures of assessment methods, and updates illustrative charts and figures;
- e) Clause 8 adds cascaded under and over voltage ride-through assessment cases, and refines simulation procedures and requirements for simulation results;
- f) Clause 9 incorporates compliance simulation and monitoring methods into power quality assessment;
- g) oscillation assessment is newly introduced, adopting combined time-domain and frequency-domain simulation as well as monitoring methods, with the consideration of renewable energy power plants connected to grid via HVDC;
- h) grid adaptability assessment is newly supplemented, specifically covering the following withstand capability, such as voltage unbalance factor, flicker and harmonics, phase angle jump and grid strength;
- i) Annex A adds topological structure examples of renewable energy power plants, compliance simulation setup, and improves contents including HIL simulation setup, monitoring of electrical performance and harmonics simulation.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
8A/233/DTS	8A/247/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

1 Scope

This document highlights the recommended technical methods of grid code compliance assessment of renewable energy (RE) power plants connected to the grid, including wind power plants, photovoltaic (PV) power plants, and hybrid power plants. Hybrid power plants refer to wind/PV power plants equipped with energy storage systems or combined power plants based on wind, PV, and energy storage. The electrical behaviour of RE power plants in this document includes the operating area, control performance, fault ride-through capability, power quality, oscillation, and grid adaptability.

Compliance assessment is the process of determining whether the electrical behaviour of RE power plants meets the specific technical requirements in grid codes or technical regulations. The assessment methods include compliance field test, compliance simulation, hardware-in-the-loop (HIL) simulation and compliance monitoring. The input for compliance assessment includes relevant supporting documents, test results, validated simulation models, controller hardware, and continuous monitoring data. This document focuses exclusively on assessment methods from a technical perspective. It does not address certification-related procedures.

This document is applicable to RE power plants connected to the electrical power grid.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-415, *International Electrotechnical Vocabulary - Part 415: Wind turbine generator systems*

IEC 61400-21-1, *Wind energy generation systems - Part 21-1: Measurement and assessment of electrical characteristics - Wind turbines*

IEC 61400-21-2:2023, *Wind energy generation systems - Part 21-2: Measurement and assessment of electrical characteristics - Wind power plants*

IEC 62934, *Grid integration of renewable energy generation - Terms and definitions*

3 Terms, definitions, abbreviated terms and subscripts

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in the IEC 61400-21-1, IEC 61400-21-2, IEC 60050-415, IEC 62934 and the following apply.

ISO and IEC also maintain terminological database for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1.1

grid code

document that recommends principles and procedures for the activities of connection, management, planning, development and maintenance of the electrical transmission and distribution grid, as well as dispatching and metering, etc

3.1.2**grid code compliance**

demonstration that the electrical behaviours of power plants satisfy specific technical requirements in grid codes or technical regulations

3.1.3**hybrid power plant**

renewable energy power plants that incorporate multiple types of energy sources, such as wind power, PV power, and energy storage systems, either in combination or individually

3.1.4**compliance monitoring**

monitoring activities with the purpose of demonstrating the ongoing compliance with the required specifications throughout the operational lifetime of the power plant

3.1.5**compliance simulation**

simulation activities conducted in a non-real-time environment, aimed at demonstrating compliance with the required specifications, particularly in cases where physical testing is impractical or carries a risk of damaging the facility

3.1.6**compliance field test**

procedure conducted on site for power plants to verify if a characteristic or a property complies with stated requirements in grid codes or technical regulations, using the electrical and control equipment

3.1.7**hardware-in-the-loop****HIL**

simulation method that allows the controller hardware under test to interact in a closed loop with a real-time simulation model

Note 1 to entry: A simulation model is used to describe the electrical topology of wind/PV power plants, and build the external real-time testing environment for the hardware. A closed loop test system is composed of the simulation and embedded physical controller under test.

[SOURCE: IEC 61400-21-2:2023, 3.15]

3.2 Abbreviated terms and subscripts**3.2.1 Abbreviated terms**

The following abbreviated terms are used in this document:

CT	current transformer
EMT	electromagnetic transient
GFM	grid forming
HIL	hardware-in-the loop
OF	over frequency
OLTC	on-load tap changer
OVRT	over-voltage ride-through
OWPP-HVDC	offshore wind power plants integrated into the grid via VSC-HVDC
OWPS	offshore wind power systems
PGU	power generation unit
POC	point of connection

PQ	active power and reactive power
PV	photovoltaic
RE	renewable energy
RMS	root mean square
RT	real-time
SCR	short circuit ratio
SCADA	supervisory control and data acquisition
STATCOM	static synchronous compensator
TS	technical specification
TSO	transmission system operator
UF	Under Frequency
UVRT	under-voltage ride-through
VSC-HVDC	voltage source converter based high voltage direct current
VT	voltage transformer

3.2.2 Subscripts

F	fault
meas	measured value
max	maximum
min	minimum
n	nominal
Omax	maximum value of over voltage fault
poc-s	variable at POC from grid
poc-c	variable at POC from power plant
ref	reference value
s	variable of grid
sa	phase A variable of grid
sb	phase B variable of grid
sc	phase C variable of grid
Umin	minimum value of under voltage fault

4 Symbols and units

In this document, the following symbols and units are used.

I_{poc}	tested results of the current at POC (A)
I_{poc-s}	harmonic currents produced by the grid (A)
I_{poc-c}	harmonic currents produced by the power plant (A)
I_s	equivalent current of the grid (A)
I_c	equivalent current of the plant (A)
P	active power of the power plant (W)
P_n	rated active power (W)
P_{meas}	measured active power (p.u.)
$P_{setpoint}$	active power setpoint value (p.u.)

P_{avail}	available active power (p.u.)
P_{lt}	maximum long-term flicker
P_{lt0}	maximum background long-term flicker
P_{ltRE}	maximum long-term flicker caused by power plant
Q_{ref}	reactive power reference value (p.u.)
Q_{meas}	measured reactive power (p.u.)
Q_{max}	maximum reactive power at POC (Var)
Q_{min}	minimum reactive power at POC (Var)
S_k	short circuit power (VA)
U_n	rated voltage at POC (V)
U_s	voltage of the grid (V)
U_{sa}	phase A voltage of the grid (V)
U_{sb}	phase B voltage of the grid (V)
U_{sc}	phase C voltage of the grid (V)
U_{max}	maximum voltage under normal operation at POC (V)
U_{min}	minimum voltage under normal operation at POC (V)
U_{Umin}	minimum value of under-voltage according to grid codes (V)
U_{Omax}	maximum value of over-voltage according to grid codes (V)
U_{poc}	tested results of the voltage at POC (V)
Z_c	equivalent impedance of the power plant (Ω)
Z_F	equivalent fault impedance (Ω)
Z_s	equivalent impedance of the grid (Ω)
Z_{sa}	phase A equivalent impedance of the grid (Ω)
Z_{sb}	phase B equivalent impedance of the grid (Ω)
Z_{sc}	phase C equivalent impedance of the grid (Ω)

5 General specifications

5.1 General

Technical requirements for RE power plants connecting to the grid are specified in the grid codes, covering aspects such as operating area, control performance, fault ride-through, power quality, oscillation, grid adaptability, etc. Some existing IEC standards such as IEC 61400-21 and IEC 61400-27, specify measurement procedures, modelling and validation methods for the electrical characteristics of wind turbines and wind power plants. This document specifies the compliance assessment methods for the electrical behaviours specified in grid codes. It applies to RE power plants, including wind power plants, PV power plants, and hybrid power plants. Information on topology examples of power plants can be found in Annex A.

Based on the commissioning and operation phases of RE power plants, three phases are emphasized, and corresponding compliance assessment methods are recommended for each. The phases are as follows:

- Planning phase
- Commissioning phase
- Commercial operation phase

Methods for compliance assessment can be classified into four general categories:

- Compliance field test
- Compliance simulation
- HIL simulation
- Compliance monitoring

In the planning phase (phase 1), a compliance simulation based on the validated power plant model is recommended. The models within the power plants should be validated to ensure higher fidelity with real performance. The models include the validated power generation unit (PGU) model and the power plant controller model. Type testing is essential for validating the PGU and other components within the plant model. HIL simulation for validating the control functionality of the PGU model is optional. Additionally, HIL simulation for the power plant can be performed if conditions are met, such as the power plant controller hardware, configuration, and parameters.

In the commissioning phase (phase 2), compliance field test, compliance simulation, and the HIL method are recommended depending on specific scenarios. Simulations in this phase should use the validated model based on the test data of power plants. The power plant model can be partially validated and can also be used in HIL simulations.

In the commercial operation phase (phase 3), compliance monitoring is recommended. Figure 1 shows the assessment procedures and methods of RE power plants.

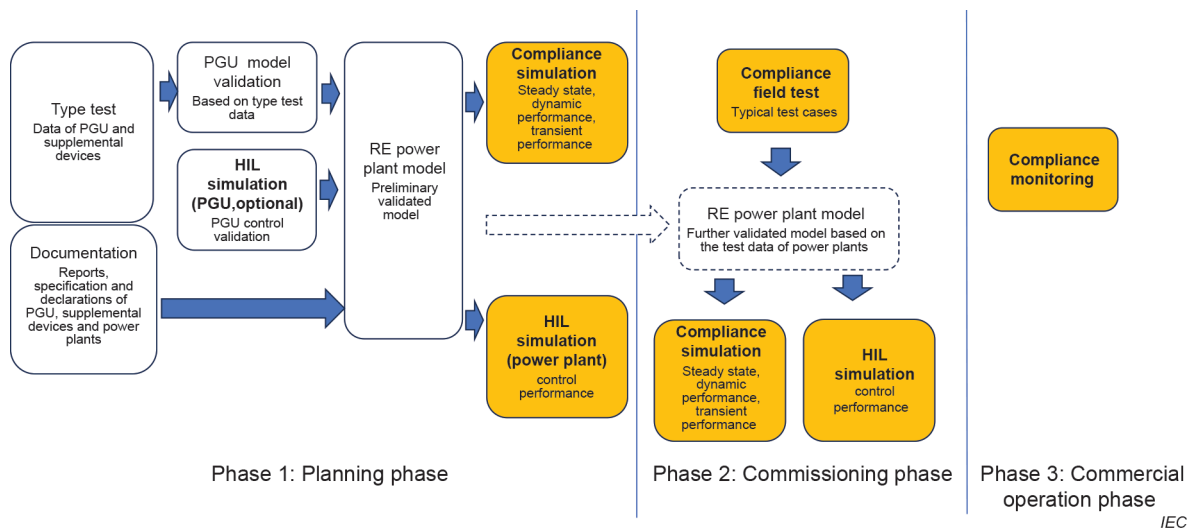


Figure 1 – Assessment procedures and methods of RE power plants

5.2 Compliance assessment methods

5.2.1 Compliance field test

Field tests are conducted at the point of connection (POC) of the power plant. For offshore wind power plants integrated into the grid via VSC-HVDC (OWPP-HVDC), field test and other assessment methods should include the POC, the point of collection, as well as HVDC receiving and sending terminals.

In this document, compliance field test focuses on steady-state operation, power quality and control performance. Steady-state operation includes reactive power capability, harmonics and flicker related to power quality. Control performance encompasses active power control, synthetic inertia response, frequency control, reactive power control, voltage slope control.

Test equipment requirements vary depending on the parameters being measured. For control performance, the existing measurement equipment at the power plant substation is generally sufficient, provided that the required values and precision meet with the relevant standards. However, specialized equipment is necessary for power quality testing. Relevant requirements can be found in IEC 61400-21-2.

5.2.2 Compliance simulation

Compliance simulation based on the plant model is a more general method suitable for early assessment prior to construction and scenarios where testing requirements cannot be fully met.

Simulation models can be categorized into different levels with detail depending on the assessment scenarios. These models can be used in compliance simulation and HIL simulation. Generally, the RE power plant model should include the PGU, reactive power compensation devices, transformer, protection devices, transmission lines, and external power system. The inclusion of a VSC-HVDC model depends on the plant configuration. The model should accurately reflect the interaction between the plant and grid regarding voltage and frequency. Models can be either electromagnetic transient (EMT) models or RMS models.

In general, most electrical performance and compliance assessments should be conducted by simulation using models, covering steady-state, dynamic performance, and transient performance. Frequency-domain analysis can be performed using simulation results, which is helpful for stability and risk assessments. Input requirements for compliance simulation include disturbances from wind and solar sources, grid voltage and frequency variations, and fault events caused by grid. Detailed information is provided in Annex B.

5.2.3 HIL simulation

The HIL method focuses on the control performance assessment of power plants and the functionality test of power plant controllers. It simulates the electrical behavior of power plants and the grid. The HIL method, which is based on physical controller hardware, can provide more accurate assessment results for control performance. However, compared to the compliance simulation method, the simulation scale might be restricted due to real-time computing capability.

Generally, HIL involves a combination of the power plant's physical controller, the simulation of the electrical grid, and the simulation of the power plant. It allows the hardware under test of the power plant controller to interact in a closed loop with a real-time simulation model.

In some cases, to achieve accurate control performance evaluation based on the physical control loop, the controllers under test can include the power plant controller, PGU controller, and controllers of reactive power compensation devices, rather than just a single type of power plant controller.