General Validation Test Program for Wind Power Generating Stations Connected to the Hydro-Québec Transmission System

April 2026

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PREAMBLE

The document entitled *Technical Requirements for the Connection of Generating Stations to the Hydro-Québec Transmission System* (July 15, 2022) [1] includes a section on requirements specific to generating stations that use inverter-based resources (IBRs). To demonstrate that these requirements are met, wind power generating station owners must conduct what are known as “validation tests” at their facilities. These tests confirm that the wind power generating station’s core functions are operational but do not cover all required testing. Three additional documents issued by Hydro-Québec set forth the full testing requirements:

- The general validation test program (this document) for all wind power generating stations. This document describes the validation tests to be conducted at wind power generating stations regardless of the specific characteristics of the facilities. This document is available on the Hydro-Québec website.
- The general validation test program for wind power generating stations connected to the Hydro-Québec transmission system, Module B – Type tests. This document describes the tests for Module B (herein). It is also available on the Hydro-Québec’s website.
- The detailed validation testing procedure specific to each wind power generating station that includes the complete sequence of validation tests for that facility. This procedure takes into account the type of wind technology used, the configuration of the grid where the generating station is connected and the particular requirements in effect at that generating station. Depending on local power system needs, the technology deployed and the settings used, Hydro-Québec may modify the general testing program and include additional tests. This procedure is generally submitted to the power producer at least two weeks before the scheduled date of the validation testing.

The first section of this document outlines the validation testing framework. The second section describes the validation tests, which are divided into eleven modules.

The power producer is strongly encouraged take the opportunity provided by the validation testing to perform all work related to NERC standards, if applicable. In this way, the testing can serve the power producer*’s* own reliability purposes. At the conclusion of this process, PSSE and EMPT simulation models reproducing the facility’s behaviour as measured during the tests must be submitted to Hydro-Québec.

DEFINITIONS

telecontrol centre
Hydro-Québec regional control centre

emission study
study report provided by the power producer demonstrating compliance with the *Emission Limits for Disturbances on the Hydro-Québec Transmission System* [2] as well as additional technical requirements related to power quality

low-voltage ride-through (LVRT)
the ability of a wind turbine to remain operational during a voltage dip

power producer
the entity responsible for the wind power generation site

terminal voltage
the voltage at the connection of the wind turbine to the collector system, specifically at the medium-voltage terminals of the wind turbine step-up transformer (typically 34.5 kV, classified as medium voltage).

1 Validation testing framework

1.1 Purpose of tests

The testing required by Hydro-Québec has two objectives:

1. To demonstrate that the wind power generating station meets Hydro-Québec's technical requirements
2. To validate the behaviours and parameters of the generating station and its numerical models, particularly those provided by the power producer to Hydro-Québec, by comparing model response to test measurements.

The tests in this document do not apply to grid-forming technologies. Validation testing for these technologies will be addressed in a procedure tailored to the project.

Should a wind power generating station include a storage system or any other combination of technologies, tests in addition to those mentioned herein are required. These will be specified in the detailed validation testing procedure.

Successful completion of the validation testing is a requirement for final acceptance of the connection by Hydro-Québec.

1.2 Testing prerequisites

Before proceeding with validation testing of the wind power generating station, several project deliverables must be completed. These are as follows:

- The wind farm settings provided by Hydro-Québec have been applied.
- The wind farm islanding study conducted by the power producer using EMT software demonstrates behaviour that allows safe testing.
- The dynamic simulation and EMT models required by Hydro-Québec have been updated and accepted by Hydro-Québec as representing the power producer's facility. These models must include the settings provided by Hydro-Québec.
- All wind farm equipment is in service. In case of phased commissioning, validation tests must be performed for each phase.
- A parameter list has been provided for the wind turbine systems, all controllers and all auxiliary equipment, including but not limited to STATCOMs, transformer tap changers and capacitor banks. Documentation providing an explanation of the parameters through flowcharts, textual descriptions and graphic representations (block diagram) has been submitted with the parameter list.
- The required signals specified in each module are available at the wind farm's main substation (high-voltage point of interconnection), enabling the recording of these signals by the equipment installed by Hydro-Québec.
- Disturbance recording systems are functional and the data is transmitted to Hydro-Québec systems.

1.3 Validation test modules

The validation tests are divided into eleven modules, as follows:

- **Module A – Primary reactive power control**
- **Module B – Low-voltage ride-through**
- **Module C – Frequency performance and inertial response**
- **Module D – Secondary voltage control**
- **Module E – Power factor**
- **Module F – Ramp rate**
- **Module G – Continuous power quality measurement**
- **Module H – Energization of the switchyard step-up transformers**
- **Module I – Frequency-dependent impedance characterization**
- **Module J – External signals**
- **Module K – Islanding performance**

1.4 Testing requirements

The results of these tests must demonstrate that the wind power generating station meets the specifications of the *Technical Requirements for the Connection of Generating Stations to the Hydro-Québec Transmission System* [1] as well as the supplemental technical requirements issued specifically for the wind farm being tested.

1.5 Testing period

Validation testing must be completed no later than six months after Hydro-Québec has accepted the commercial operation of each generating station phase.

Module A tests are performed on a single turbine and can therefore be run before all turbines are in service. Module B is addressed in a separate document, as mentioned in section 2.2. Discussions with the turbine manufacturer and Hydro-Québec are strongly recommended so these tests can be scheduled as early as possible given their complexity and the equipment and logistics involved.

Module H tests and the first series of Module K tests are also performed before all turbines are in service, as soon as the conditions are met.

The tests of modules C, D, E, F, I and J, as well as the second series of Module K tests, are performed on the generating station as a whole and are preferably run once all turbines are in service and without generation restrictions. Module C is an exception: if the power producer*'s* systems do not allow Module C testing of the generating station as a whole, a single turbine is tested.

If the voltage controller or any other device (e.g., synchronous condenser, static compensator or shunt reactor) within the wind farm might affect the generating station's test performance, it must be in service unless otherwise specified in the detailed test procedure. Note that in case of phased commissioning, validation testing must be repeated for each phase.

Module G tests use a monitoring system (see Section 1.8) to validate compliance with power quality requirements during generating station operation. It is recommended that this system be installed before connection so the voltage supplied by the transmission system at the point of interconnection can be measured. This measurement is used to assess pre-existing voltage harmonics (see Section 2.7.2.2).

All testing must be coordinated with Hydro-Québec in the weeks and days leading up to the tests and with the dispatcher of the relevant telecontrol centre on the day of testing.

It is strongly recommended that the power producer use the validation testing period to carry out the regulatory activities required to update, verify and validate its wind farm models in the simulation tools.

1.6 Roles of the power producer and Hydro-Québec

The power producer is required to carry out validation tests to demonstrate that its facilities meet Hydro-Québec's requirement. The power producer must notify Hydro-Québec of the intended testing window at least three months in advance and must promptly inform Hydro-Québec of any change to this window.

Hydro-Québec provides the power producer with a detailed validation testing procedure at least two weeks before the scheduled testing date.

The power producer must allow Hydro-Québec to install instrumentation at the power producer's facilities to conduct testing and analyze results, including a monitoring system at the point of interconnection, the switchyard high-voltage bus, a feeder or a turbine. The monitoring system may record signals continuously or on detecting threshold exceedances associated with disturbances. Such signals are primarily electrical voltages and currents but may also be mechanical variables or other signals. The power producer must also supply and install spare fibre-optic cables and communication links that Hydro-Québec may use for testing or continuous monitoring (see Section 2 for required recordings for each test module). The power producer must perform the necessary outages of for installation and removal of the instrumentation at no cost to Hydro-Québec.

The power producer must test one wind turbine to verify compliance with low-voltage ride-through requirements described in the *Technical Requirements for the Connection of Generating Stations to the Hydro-Québec Transmission System* [1]. If different types of wind turbines (different technologies, settings or software versions) are used in the same wind power generating station, one turbine of each type must be tested.

Hydro-Québec may attend the testing or allow an independent third party to represent it for purposes of certifying the validity of the tests. If the power producer wishes to demonstrate compliance with the low-voltage ride-through requirements (Module B) off site in collaboration with the manufacturer (through test laboratories or power hardware-in-the loop (PHIL), for example), the power producer must notify Hydro-Québec, which reserves the right to accept or refuse the proposal. The document entitled *General Validation Testing Program for Wind Power generating stations Connected to the Hydro-Québec Transmission System, Module B – Type Tests* mentioned in Section 2.2, Module B – low-voltage ride-through performance, describes these options in greater detail.

1.7 Certification

If Hydro-Québec deems the test results conclusive, the wind power generating station is considered to meet Hydro-Québec's requirements regarding the topology and software version (turbine and generating station controllers) verified at the time of testing. Throughout the operational life of the wind power generating station, the power producer must notify Hydro-Québec if a new software version is deployed and document the modifications in that version. Prior to implementing the change, the power producer must submit to Hydro-Québec a request for a qualified change[1] in accordance with Hydro-Québec and NERC guidelines and procedures. Hydro-Québec may, in either case, require that all or some validation tests be rerun at the power producer's expense.

Hydro-Québec may waive the requirement for certain parts of the validation testing for generating stations whose design, parameters, turbine type and controller software version have already successfully completed the validation testing program at a generating station integrated into the Hydro-Québec grid. In addition, tests to confirm low-voltage ride-through capability may not be required if the power producer provides a comprehensive report on tests performed on an identical wind turbine (running the same software version) demonstrating to Hydro-Québec's satisfaction that it meets Hydro-Québec requirements.

1.8 Monitoring system

Certain verifications are performed throughout the operational life of the wind farm using a monitoring system in accordance with applicable reliability standards—power quality requirements (Module G), for example. This monitoring is also useful for the other modules, since staged testing only verifies a limited number of operating conditions and disturbances. It can also be used to validate system performance and simulation models.

1.9 Measurement instrumentation

The instruments used by the power producer to record the tests must have the following minimum technical characteristics:

- Digital instrumentation, to facilitate correlation of test results with numerical simulation results
- Fast and simple recording start and data recovery
- Accuracy: 16 bits
- Minimum of 16 channels
- Adjustable anti-aliasing filters or sigma-delta technology
- Sampling rates and recording durations that an adjusted to test requirements: a voltage controller step response requires a sampling rate of at least 10 kHz and a recording duration of about 30 seconds, for example, while a step response to verify an overexcitation limiter may require recording over several minutes but a reduced sampling rate of 2 kHz would be sufficient

1. Hydro-Québec, definition of qualified change (modification substantielle désignée) for Québec. Available in French only at https://www.hydroquebec.com/data/transenergie/raccordement-reseau/definition-modification-fac-002-4_2024-09-26.pdf

1.10 Periodic verification

The frequency of periodic verifications must comply with NERC standards at a minimum. The power producer must, at its own expense, perform such tests and provide appropriate conditions, specifically for installation of the necessary instrumentation. The power producer shall propose a testing program that meets NERC requirements. Hydro-Québec reserves the right to request additional tests and, if necessary, to assist the power producer in executing the tests.

2 Description of the validation tests

2.1 Module A – Primary reactive power control

Primary reactive power control is performed by a local control loop at the wind turbine. Generally, the dynamic response of this control loop characterizes the fast (transient) reactive power control of the wind farm. The following program applies to this general scenario, where the reactive power required for control is provided solely by the wind turbines. However, if fast reactive power control is provided by other supplementary equipment (compensators, for example), a specific test procedure is executed to assess the transient response of this equipment and determine if it meets requirements.

2.1.1 Purpose

These tests are designed to measure the local dynamic response of a wind turbine to rapid voltage change and to validate that this response meets fast reactive control requirements.

2.1.2 Test descriptions

The tests are conducted on a single wind turbine, which must be isolated from any secondary voltage or reactive power control systems. For each test, wind turbine output must exceed 30% of rated capacity, or meet the manufacturer's recommendations.

The Part 1 tests consist of inducing small instantaneous variations in voltage on the medium-voltage side of the wind turbine (terminal voltage). If a test bench is available that isolates the wind turbine via an impedance and allows terminal voltage control, it will generate the voltage changes. Otherwise, voltage changes are generated by grid switching operations (switching of capacitor banks, reactors, etc.) or by changing the tap positions of switchyard power transformer(s).

The Part 2 tests consist of introducing small step changes in voltage or Mvar setpoint of short duration directly into the wind turbine’s voltage/reactive power control system. These tests are only possible if the turbine has an accessible control system.

The Part 3 tests involve observing the wind turbine’s default primary control value upon loss of communication with the controller at the facility’s point of interconnection and once communication is restored.

If the power producer wishes to use power-hardware-in-the-loop (PHIL) or software-in-the-loop (SIL) test benches to conduct the tests on the wind turbine, the power producer may propose a testing procedure to Hydro-Québec. Hydro-Québec reserves the right to reject the methods if the procedure is deemed inadequate for observing the desired behaviour.

2.1.2.1 Part 1 – External disturbances

Test A1.1 Instantaneous ≈2% rise in terminal voltage

Test A1.2 Instantaneous ≈2% drop in terminal voltage

Test A1.3 Instantaneous ≈5% rise in terminal voltage

Test A1.4 Instantaneous ≈5% drop in terminal voltage

2.1.2.2 Part 2 – Setpoint changes

Test A2.1 Positive step of ≈2% in voltage reference or ≈5% in reactive power reference lasting 0.5 to a few seconds

Test A2.2 Negative step of ≈2% in voltage reference or ≈5% in reactive power reference lasting 0.5 to a few seconds

Test A2.3 Positive step of ≈5% in voltage reference or ≈10% in reactive power reference lasting 0.5 to a few seconds

Test A2.4 Negative step of ≈5% in voltage reference or ≈10% in reactive power reference lasting 0.5 to a few seconds

2.1.2.3 Part 3 – Communication loss

Test A3.1 Loss of communication between the wind turbine and the generating station controller and restoration of communication. The voltage or reactive power setpoint must be different from the programmed default setpoint.

2.1.3 Recordings

The following signals are to be recorded at the wind turbine:

- Three-phase voltages on the low-voltage side of the turbine transformer. For technologies with different voltage levels at the stator and the converter, the three-phase voltages for both are required.
- Three-phase currents on the low-voltage side of the turbine transformer. For technologies with different current levels at the stator and the converter, the three-phase currents for both are required.

2.2 Module B – Low-voltage ride-through performance

Module B is addressed in a separate document entitled *General Validation Testing Program for Wind Power generating stations Connected to the Hydro-Québec Transmission System, Module B: Type Tests*, as this module is site-independent and specific to the technology, insofar as it covers similar parameter groups and functionalities with respect to short-circuit ratios, subsynchronous operations and control strategies during disturbances. Successful completion of these Module B tests is nonetheless required for validation testing acceptance.

2.3 Module C – Frequency performance and inertial response

2.3.1 Purpose

These tests are designed to verify that the wind turbines meet frequency control requirements (frequency behaviour and inertial response).

2.3.2 Test descriptions

The tests are performed with at least 95% of the wind turbines in service and generating, or with a maximum of one turbine out of service. The more permissive condition applies.

The tests involve applying frequency signals of short duration directly to the wind farm's frequency control system via a dedicated test input provided by the turbine manufacturer. The frequency return ramp rate is always set at 0.05 Hz/s following a 30-second stabilization period starting when the event ends.

2.3.2.1 Part 1 – Underfrequency behaviour

Test	Frequency nadir (Fmin)	Rate of change (r)	Required output	Pre-test remote power limit setpoint
C1.1	58.5 Hz	5 Hz/s	Between 30% and 90%	None
C1.2	59.0 Hz	0.1 Hz/s	Between 30% and 90%	None
C1.3	58.5 Hz	5 Hz/s	Between 50% and 90%	30%
C1.4	59.0 Hz	0.1 Hz/s	Between 50% and 90%	30%
C1.5	Repeat C1.1 tests twice consecutively at two-minute intervals			
C1.6	Repeat C1.3 tests twice consecutively at two-minute intervals			

2.3.2.2 Part 2 – Underfrequency behaviour

Test	Maximum frequency (Fmax)	Rate of change (r)	Required output	Active power reduction setpoint
C2.1	60.35 Hz	0.05 Hz/s	Between 30% and 90%	None
C2.2	60.8 Hz	0.05 Hz/s	Between 30% and 90%	Now
C2.3	61.0 Hz	0.1 Hz/s	Between 50% and 90%	None
C2.4	61.2 Hz	5.0 Hz/s	Between 50% and 90%	None

2.3.3 Recordings

The following signals are to be recorded. Additional equipment may have to be installed depending on the design of the wind facility:

- Three-phase voltages on the low-voltage side of the turbine transformer. For technologies with different voltage levels at the stator and the converter, the three-phase voltages for both are required.
- Three-phase currents on the low-voltage side of the turbine transformer. For technologies with different current levels at the stator and the converter, the three-phase currents for both are required.
- Single-phase voltage on the medium-voltage side of the generating station step-up transformers
- Three-phase voltages at the wind farm point of interconnection
- Three-phase currents at the wind farm point of interconnection
- Rotor speed, blade pitch and wind speed for the same turbine
- Frequency control system input and output signals

2.4 Module D – Secondary voltage control

Secondary voltage control supplements primary control and can replace it when sufficiently fast. It can control voltage on the high-voltage side of the power producer's facilities (or at the point of interconnection). The following test program applies when the secondary control loop is managed by a system, which we call the voltage controller, that controls the reactive power output of the wind turbines based on a voltage setpoint at the high-voltage side of the switchyard. This program thus applies to the general case where reactive power is supplied solely by the wind turbines. If voltage control is provided by supplementary equipment (dynamically switched compensators and/or shunt reactors, for example), a specific test procedure is executed to assess the response of this equipment and determine if it meets requirements.

2.4.1 Purpose

The tests are designed to measure the response of the secondary voltage control system and to verify that this response, complementing the primary control, allows voltage control requirements to be met.

The tests are also used to verify voltage droop control and performance when the wind farm supplies only reactive power—referred to as STATCOM mode.

Lastly, the tests also serve to verify the reactive power dynamics at the generating station when the voltage controller is in service or offline.

2.4.2 Test descriptions

The tests are performed with at least 95% of the wind turbines in service and generating, or with a maximum of one turbine out of service. The more permissive condition applies. Generating station output must exceed 30% of rated capacity for test series D1 through D3. For the DS test series, the generating station must be operating in STATCOM mode, with output at zero. Hydro-Québec may require certain specific operating conditions, such as the rotor being at a standstill for Type 3 turbines.

The D1 tests involve inducing small variations in voltage on the grid by switching operations (switching of capacitor banks, shunt reactors, tap changers, etc.).

The D2 tests involve applying the setpoint steps of the wind farm voltage controller.

The D3 tests consist of disabling the voltage controller and returning it to service once reactive power at the turbines has stabilized. The tests are run using a pre-test setpoint that differs from the programmed default setpoint.

The DS tests consist of rerunning the D1, D2 and D3 tests with the generating station operating in STATCOM mode to validate its performance.

If the facility includes dynamically switched shunt devices, the tests must be run with and without this equipment. To demonstrate its dynamic regulation capability, the facility must meet performance expectations without switching shunt devices for at least 30 seconds.

The generating station must be configured with the droop established by generating station settings prior to testing. The tests are then rerun with zero droop, or a different droop setting if required by the test

approval engineer. Likewise, these tests may be rerun for different generating station control modes (voltage control, reactive power control, power factor control, etc.).

Any change in reference or setpoint must be instantaneous and not ramped.

2.4.3 List of tests

Test	Voltage step	Step type	Required output	Droop
D1.1	2%	Grid voltage increase	30% to 100%	Yes
D1.2	- 2%	Grid voltage decrease	30% to 100%	Yes
D1.3	+ 5%	Grid voltage increase	30% to 100%	Yes
D1.4	- 5%	Grid voltage decrease	30% to 100%	Yes
D1.5	-5% followed by +5% after a few seconds	Grid voltage decrease and increase	30% to 100%	Yes
D2.1	+ 2%	Setpoint increase	30% to 100%	Yes
D2.2	- 2%	Setpoint decrease	30% to 100%	Yes
D2.3	+ 5%	Setpoint increase	30% to 100%	Yes
D2.4	- 5%	Setpoint decrease	30% to 100%	Yes
D2.5	-5% followed by +5% after several seconds	Setpoint decrease and increase	30% to 100%	Yes
D3.1	Disable the voltage controller until turbine output has stabilized. Generating station output must be between 30% and 100%. The generating station must generate reactive power equal to 50% of rated capacity. This setpoint must differ from the default value. Return the voltage controller to service and verify that the generating station returns to its setpoint within 10 minutes.			Yes
Tests in STATCOM mode				
DS1.1	+ 2%	Grid voltage increase	0%	Yes
DS1.2	- 2%	Grid voltage decrease	0%	Yes
DS1.3	+ 5%	Grid voltage increase	0%	Yes
DS1.4	- 5%	Grid voltage decrease	0%	Yes
DS1.5	-5% followed by +5% after several seconds	Grid voltage decrease and increase	0%	Yes

DS2.1	+ 2%	Setpoint increase	0%	Yes
DS2.2	- 2%	Setpoint decrease	0%	Yes
DS2.3	+ 5%	Setpoint increase	0%	Yes
DS2.4	- 5%	Setpoint decrease	0%	Yes
DS2.5	-5% followed by +5% after several seconds	Setpoint decrease and increase	0%	Yes
DS3.1	Disable the voltage controller until turbine output has stabilized. The generating station must be in in STATCOM mode and generating reactive power equal to 50% of rated capacity. This setpoint must differ from the default value. Return the voltage controller online and verify that the generating station returns to its setpoint within 10 minutes.			

2.4.4 Recordings

The following signals are to be recorded:

- Three-phase voltages on the low-voltage side of the turbine transformer. For technologies with different voltage levels at the stator and the converter, the three-phase voltages for both are required.
- Three-phase currents on the low-voltage side of the turbine transformer. For technologies with different current levels at the stator and the converter, the three-phase currents for both are required.
- Single-phase voltage on the medium-voltage side of the generating station step-up transformers
- Three-phase voltages at the wind farm point of interconnection
- Three-phase currents at the wind farm point of interconnection
- Rotor speed, blade pitch and wind speed for the same turbine

2.5 Module E – Power factor

The following test program addresses the general case where the generating station's dynamic reactive power is generated solely by the wind turbines. In cases where power factor compliance is achieved using supplementary equipment (compensators and/or shunt reactors, for example), a specific test procedure is executed to determine if requirements are met.

2.5.1 Purpose

The purpose of these tests is to verify that the wind farm meets power factor requirements and to measure the maximum reactive power capability of both the wind farm as a whole and an individual turbine.

2.5.2 Test descriptions

The tests are ideally run with all the generating station's wind turbines in service. Depending on the test, the output of the turbines in service ranges from 10% to 100% of rated capacity. In some cases, Hydro-Québec may agree to run the tests with fewer wind turbine in service and extrapolate the results to determine the generating station's maximum reactive power generation (or absorption). Local grid voltage restrictions may also require that the tests be performed with a limited number of turbines.

The tests involve maximum reactive power generation and absorption at different output levels across a voltage range of 0.90 pu to 1.10 pu on the high-voltage side of the switchyard.

These tests may require changes to the voltage control system setpoints.

Test E1	Turbines at 100% of rated capacity, maximum capacitive reactive power for 1 hour
Test E2	Turbines at 100% of rated capacity, maximum inductive reactive power for 1 hour
Test E3	Turbines at 10% of rated capacity, maximum capacitive reactive power for 1 hour
Test E4	Turbines at 10% of rated capacity, maximum inductive reactive power for 1 hour
Test E5	Turbines in STATCOM mode, maximum capacitive reactive power for 1 hour
Test E6	Turbines in STATCOM mode, maximum inductive reactive power for 1 hour

2.5.3 Recordings

The following signals are to be recorded:

- Three-phase voltages on the low-voltage side of the turbine transformer. For technologies with different voltage levels at the stator and the converter, the three-phase voltages for both are required.
- Three-phase currents on the low-voltage side of the turbine transformer. For technologies with different current levels at the stator and the converter, the three-phase currents for both are required.
- Single-phase voltage on the medium-voltage side of the generating station step-up transformers

- Three-phase voltages at the wind farm point of interconnection
- Three-phase currents at the wind farm point of interconnection
- Rotor and wind speed for the same turbine

2.6 Module F – Ramp rate

The following test program assumes the wind farm is operating in steady state without disturbances and with power ramp setpoints enabled. The detailed test procedure provides further information on the test sequence.

2.6.1

The purpose of these tests is to verify that the wind farm meets maximum ramp rate requirements when started or shut down using a ramp controller.

2.6.2 Test descriptions

The tests consist of a generating station shut-down sequence followed by a generating station start-up sequence to verify that applied ramp rates are followed.

The tests are performed with at least 95% of the wind turbines in service and generating, or with a maximum of one turbine out of service. The more permissive condition applies. Wind turbine output must exceed 50% of rated capacity.

Test F1 Complete generating station shutdown

Test F2 Generating station startup

Test F3 Apply a power limit reducing output from 100% to 50% of the current generating station production

Test F4 Remove the power limit reducing output to 50%

Test F5 Apply a power limit reducing output from 100% to 50% of the current generating station production. Next, with a voltage setpoint active and the generating station in voltage control mode with droop, disable the communication link between the generating station controller and the wind turbines while the generating station is curtailed. The test continues until the generating station reaches steady state.

2.6.3 Recordings

The following signals are to be recorded:

- Three-phase voltages on the low-voltage side of the step-up transformer of one turbine
- Three-phase voltages on the low-voltage side of the turbine transformer. For technologies with different voltage levels at the stator and the converter, the three-phase voltages for both are required
- Three-phase currents on the low-voltage side of the turbine transformer. For technologies with different current levels at the stator and the converter, the three-phase currents for both are required
- Three-phase voltages at the wind farm point of interconnection

- Three-phase currents at the wind farm point of interconnection
- Rotor speed, blade pitch and wind speed for the same turbine

2.7 Module G – Continuous power quality monitoring

A monitoring system installed by Hydro-Québec (see Section 1.8) continuously evaluates or records power quality parameters and disturbance levels throughout the operational life of the wind power generating station. In principle, this system makes it possible to do the following:

- Verify compliance with *Emission Limits for Disturbances on the Hydro-Québec Transmission System* [2], as demonstrated in the emission study provided by the power producer
- Monitor supply voltage quality to ensure alignment with the *Characteristics and target values of the voltage supplied by the Hydro-Québec transmission system* [3]
- Support system studies and event analysis, together with data gathered at other metering points on the Hydro-Québec grid

The measurements and assessments must, however, be performed in a controlled environment to simplify verification and ensure rigorous interpretation of results.

As stated in Section 3.6 of reference [2], Hydro-Québec may require a new assessment of compliance with emission limits as well as the implementation of mitigation measures or operating restrictions for the facility should it not comply with emission limits.

2.7.1 Purpose

The purpose of these tests is to:

- Characterize the performance of the measurement chain.
- Verify that the voltage transformer (or the voltage measurement chain) meets applicable accuracy requirements, including compliance with the 0.5-WB1 accuracy class extension for harmonic frequencies up to 3 kHz, as defined in Table 8 of international standard IEC 61869-1:2023 [4] (latest revision).
- Measure voltage supplied by the Hydro-Québec transmission system at the high-voltage point of interconnection without the generating station’s influence, specifically to assess pre-existing voltage harmonics.
- Verify that power quality disturbance levels remain within the emission limits applicable to the wind farm at the high-voltage point of interconnection point as established in the emission study.

2.7.2 Test descriptions

This module generally demonstrates compliance with power quality requirements through continuous monitoring at the wind farm’s high-voltage point of interconnection rather than through staged tests, with the exception of the accuracy performance assessment of the measurement chain.

In the event of technical specifics or inconclusive results, supplemental measurements or specific tests may be performed as per a protocol accepted by Hydro-Québec.

2.7.2.1 Measurement chain and voltage transformer accuracy

Hydro-Québec assesses the accuracy performance of the voltage and current measurement chains and the voltage transformers at ambient temperature for each phase.

Measurement chain accuracy performance includes, where necessary, applying a correction factor to the recorder. Any such correction factor, along with the manufacturer's calibrated transformation ratio for the instrument transformers, must be documented. If the transformation ratio is not available, it may be measured during testing.

Performance assessment is carried out using Hydro-Québec's instrumentation and the detailed validation testing procedure specific to the generating station.

2.7.2.2 Voltage supplied by the Hydro-Québec transmission system

Voltage across all three phases is measured at the high-voltage point of interconnection, without the influence of the wind farm, over a period agreed upon by the power producer and Hydro-Québec. All generating station equipment capable of influencing voltage disturbance levels must be offline—in particular, harmonic-generating equipment and capacitive equipment that could interact with the Hydro-Québec transmission system, including the medium-voltage collector system.

Connecting the switchyard step-up transformers at no-load or supplying station services is generally acceptable.

2.7.3 Power quality under generating station operating conditions

Power quality disturbance levels are assessed at the high-voltage point of interconnection, in accordance with Appendix B of reference document [2], and then compared to the emission limits applicable to the wind farm as established in the emission study.

The emission limits cover harmonics, interharmonics, rapid voltage changes, short-term flicker and current unbalance.

In the event of an exceedance, an emission level analysis is performed using the measured data. If the analysis is inconclusive, additional testing and measurements may be required using a measurement protocol approved by Hydro-Québec.

2.7.4 Recordings

2.7.4.1 Accuracy of measurement chain and voltage transformers

At a minimum, the following accuracy parameters must be assessed or provided:

- For each measurement chain and for all three phases:
    - Transformation ratio of the instrument transformers as calibrated by the manufacturer or measured by Hydro-Québec

- Amplitude and phase measurement accuracy at the fundamental frequency for the relevant power quality parameter, particularly for phase voltage and fundamental voltage

- For each measurement chain type and each voltage transformer model:
  - Frequency response up to 10 kHz
  - Ratio error at frequencies up to 3,000 Hz, expressed as a percentage
  - Phase error at frequencies up to 3,000 Hz, expressed in degrees

2.7.4.2 Continuous monitoring

Continuous monitoring at the point of interconnection includes continuous data logging as well as event-triggered recordings (threshold exceedances).

The power quality parameters to be recorded are consistent with those monitored by Hydro-Québec's transmission system recorders, specifically voltage, current, power and phase angle for each of the three phases as well as the neutral current, if needed. These parameters are primarily defined in reference documents [2] and [3].

Additionally, for certain voltage and current harmonics or interharmonics, values aggregated over each 180-cycle interval (or equivalent), in accordance with standard IEC 61000-4-30 Class A of [5], must be recorded for the following parameters:

- Positive, negative and zero-sequence phasors, based on Fortescue's symmetrical components, where:
  - Amplitude is expressed as a percentage of the fundamental frequency positive sequence component
  - The dominant phase angle is calculated according to Equation D.3 of standard IEC 61400-21-1 [6] and expressed in degrees
- Phase-voltage and bus-current phasors, as required

Harmonic orders and any additional accuracy requirements will be specified in the detailed test procedure.

Data must be provided in CSV format, or COMTRADE format for waveforms. Measurements and their timestamps must be synchronized to UTC (Coordinated Universal Time) in accordance with standard IEC 61000-4-30 Class A [5].

2.8 Module H – Energization of the switchyard step-up transformers

While the continuous power quality monitoring described in Section 2.7 allows verification of emission limit compliance throughout the operational life of the generating station, staged testing during energization of the switchyard step-up transformers is intended to provide more precise data for a rigorous interpretation of the results.

2.8.1 Purpose

The tests are designed to measure and characterize voltage changes caused by the energization of the switchyard step-up transformers, with any mitigation measures applied, for comparison with the results presented in the emission study and the limits defined in Section 7.7.4 of the *Technical Requirements for the Connection of Generating Stations to the Hydro-Québec Transmission System* [1].

2.8.2 Test descriptions

The voltage changes caused by each energization of the switchyard step-up transformers are measured and characterized by the parameters mentioned in Section 2.8.3. The energizations are performed under no-load conditions, with mitigation where applicable, according to the sequence specified in the emission study. If more than one sequence is called for, each sequence must be executed as specified in the emission study.

Measurements must be taken during at least four energizations of each high-voltage step-up transformer.

The maximum voltage change and the rapid voltage change (RVC) index are compared to the limits defined in Section 7.7.4 of reference document [1].

2.8.3 Recordings

For each energization, the following signals and parameters are recorded on the high-voltage side of the switchyard:

- Three-phase high voltage:
    - RMS voltage change calculated over a sliding one-cycle window (fundamental frequency) refreshed every half-cycle, in accordance with standard IEC 61000-4-30 Class A [5]
    - Maximum RMS voltage change relative to the arithmetic mean of the RMS values over approximately one second immediately preceding the energization, in accordance with standard IEC 61000-4-30 Class A [5]; this change is expressed as a percentage of the nominal voltage of the high-voltage grid
    - Rapid voltage change (RVC), calculated using the method set out in Appendix B1 of the *Emission Limits for Disturbances on the Hydro-Québec Transmission System* [2]
    - RVC start time, in accordance with standard IEC 61000-4-30 Class A [5]; the detection threshold is typically set at 2.5% of nominal voltage but may be reduced if necessary to record changes of small magnitude

    - RVC duration, in accordance with standard IEC 61000-4-30 Class A [5]; start and end thresholds are identical
    - Voltage waveforms
- Three-phase high-voltage current for each step-up transformer
    - Waveforms synchronized with voltage waveforms
    - Peak current during the voltage change
- Calculated magnetic flux in each step-up transformer for all three phases, based on voltage measurement on the wind farm side of the step-up transformer breaker

During a voltage change caused by a step-up transformer energization, waveform recording and voltage change characterization must continue even if a power-frequency dip or temporary overvoltage is detected.

2.9 Module I – Frequency-dependent impedance characterization

2.9.1 Purpose

These tests are intended to verify frequency-depended impedance, particularly that of the inverters and the wind farm, under different operating conditions, to allow validation of the data used in the emission study.

2.9.2 Test descriptions

Frequency-dependent impedance, expressed as magnitude and angle or as resistance and reactance, is characterized based on measurements taken:

- Over the entire frequency range of interest, including subsynchronous, harmonic and interharmonic frequencies
- Under different possible operating conditions, accounting for presence or absence of equipment likely to influence the results
- For Fortescue symmetrical components: positive, negative and, where applicable, zero-sequence

The results must be sent to Hydro-Québec if the latter did not perform the tests. Hydro-Québec reserves the right to request a revision of the emission study.

Frequency-dependent impedance characterization involves injecting a multi-frequency current into the generating station to induce voltages across the impedance being characterized at various measurement points. The transfer function between voltage and current is then calculated at each point to obtain the impedance as a function of frequency.

The current injection point and the measurement points must allow determination of the frequency-dependent impedance of each component, including the following:

- Power transformers
- Capacitor banks or harmonic filters
- Main feeder cables of the collector system
- The various wind turbine models

The tests must be executed under the following conditions:

- Three different active power levels for the turbines, at least two of which must have a minimum spread of 30% of turbine rated power
- STATCOM turbine control mode (0% active power), if this mode is supported in the generating station
- Excluding turbine impedance effects (specifically, without filters and the inverter), for example, by opening the turbine medium-voltage breakers

Whenever possible, the grid frequency-dependent impedance at the generating station’s high-voltage point of interconnection is also characterized and recorded for each test.

Measurement points are generally located as follows:

- On the high-voltage side of the switchyard
- On the medium-voltage side of the switchyard
- At the primary or secondary side of the power transformer for at least two turbines (if possible)

The exact location of current measurement shall be determined by Hydro-Québec in the detailed test procedure.

The injection point for the multi-frequency current is generally located on the medium-voltage side of the switchyard.

2.9.3 Recordings

The following signals are to be recorded at each measuring point for assessment of the relevant Fortescue symmetrical components across the entire frequency range of interest:

- Voltage on each of the three phases
- Current on each of the three phases

The instrumentation used must have sufficient accuracy for frequencies up to at least 3,000 Hz. The measurement chain must be characterized, particularly the voltage transformers.

For each test, the following parameters must be recorded at the measurement points for each targeted wind turbine as well as on the high-voltage side of the generating station switchyard:

- Three-phase active and reactive power at fundamental frequency generated by the turbines and by the wind farm
- The negative sequence voltage unbalance (U_2/U_1) at fundamental frequency at the different voltage measuring points
- Outdoor temperature
- Timestamps
- Any other parameter used to characterize test conditions that might influence the results (e.g., turbine wind speed, rotor speed, blade pitch angle, etc.); all such data must be from the same turbine

2.10 Module J – External signals

2.10.1 Purpose

These tests are designed to verify that the wind farm meets requirements regarding signals from external systems to ensure these signals perform their intended functions with respect to data logging, operational setpoints and telemetry transmission to Hydro-Québec systems.

2.10.2 Test descriptions

The wind farm must be operating at between 50% and 100% of its rated capacity.

Test J1 Issue a slow curtailment setpoint at 20%, 50% and 75% of the generating station's available capacity based on wind conditions, followed by removal of the setpoint once the curtailed generating station reaches steady state.

Test J2 Issue a voltage setpoint of 0.98 pu of the nominal voltage on the high-voltage side of the wind farm substation, with the generating station in voltage control mode with droop.

Test J3 Issue a voltage setpoint of 1.02 pu of the nominal voltage on the high-voltage side of the wind farm substation, with the generating station in voltage control mode with droop.

Test J4 Issue a voltage setpoint of 0 pu of the nominal voltage on the high-voltage side of the interconnection substation, with the generating station in voltage control mode with droop.

Test J5 Issue a voltage setpoint of 10 pu of the nominal voltage on the high-voltage side of the interconnection substation, with the generating station in voltage control mode with droop.

Test J6 Deactivate the telecommunication link between Hydro-Québec and the power producer while the generating station is curtailed, a voltage setpoint is active and the generating station is operating in voltage control mode with droop. The test continues until the generating station reaches steady state and telecommunications are restored.

2.10.3 Recordings

The following signals are to be recorded:

- Three-phase voltages on the low-voltage side of the wind turbine transformer. For technologies with different voltage levels at the stator and the converter, the three-phase voltages for both are required.

- Three-phase currents on the low-voltage side of the turbine transformer. For technologies with different current levels at the stator and the converter, the three-phase currents for both are required.
- Single-phase voltage on the medium-voltage side of the generating station step-up transformers
- Three-phase voltages at the wind farm point of interconnection
- Three-phase currents at the wind farm point of interconnection
- Rotor speed, blade pitch and wind speed for the same turbine

2.11 Module K – Islanding behaviour

2.11.1 Purpose

These tests are designed to verify that the wind power generating station does not disturb the grid unduly when suddenly islanded, with or without load, following a contingency. They also verify that overvoltages are not excessive in magnitude, duration and harmonic content. The wind farm islanding study conducted by Hydro-Québec prior to the tests, using the provided transient numerical models, must demonstrate satisfactory performance to allow the tests to proceed. The power producer must also provide Hydro-Québec with the parameter files and control system version, which must be consistent with those delivered with the simulation models submitted to Hydro-Québec.

2.11.2 Test descriptions

The tests are conducted in two stages:

- A first series is performed when at least 30% of the wind turbines in the generating station are synchronized to the grid.

- A second series is performed when at least 95% of the turbines are in service and producing power, or with a maximum of one turbine out of service. The more permissive condition applies.

The wind farm must be operating at between 10% and 20% of its rated capacity, unless the test engineer indicates otherwise.

Opening the facility's main circuit breaker must island the generating station with no load other than the station services load (which must be negligible relative to total output). No high-voltage or medium-voltage fast grounding on the transformer substation side may be activated during the test. Test K1 is repeated twice for each of the two stages.

Test K1 Open the high-voltage circuit breaker connecting the wind farm to the point of interconnection with the Hydro-Québec grid. The reactive power exchange measured at the point of interconnection must be zero, or another value determined by the test engineer based on system constraints.

2.11.3 Recordings

The following signals are to be recorded:

- Three-phase voltages on the low-voltage side of the turbine transformer. For technologies with different voltage levels at the stator and the converter, the three-phase voltages for both are required.

- Three-phase currents on the low-voltage side of the turbine transformer. For technologies with different current levels at the stator and the converter, the three-phase currents for both are required.

- Single-phase voltage on the medium-voltage side of the generating station step-up transformers

- Three-phase voltages at the wind farm point of interconnection
- Three-phase currents at the wind farm point of interconnection
- Rotor speed, blade pitch and wind speed for the same turbine

3 References

[1] *Technical Requirements for the Connection of Generating Stations to the Hydro-Québec Transmission System*, Decision D-2022-088 – effective July 15, 2022. Online at the public Hydro-Québec website. https://www.hydroquebec.com/data/transenergie/pdf/Exigences_raccordement_centrales_ang_2022-07-15.pdf

[2] *Emission Limits for Disturbances on the Hydro-Québec Transmission System* – effective July 15, 2022. https://www.hydroquebec.com/data/transenergie/pdf/Limites-emission_ang_2022-07-15.pdf

[3] *Characteristics and target values of the voltage supplied by the Hydro-Québec transmission system,* December 2016. http://www.xitizap.com/hydro-quebec.pdf

[4] *Instrument transformers – Part 1: General requirements*. International standard IEC 61869-1:2023.

[5] *Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques - Power quality measurement methods*. International standard IEC 61000-4-30:2025.

[6] *Wind energy generation systems – Part 21-1: Measurement and assessment of electrical characteristics - Wind turbines*. International standard IEC 61400-21-1:2019.