Hydro Québec
TransÉnergie

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

Direction Planification des actifs et expertise de transport

February 2011

TABLE OF CONTENTS

PREAMBLE

The document *Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Québec Transmission System* contains a specific section for requirements associated with wind generation. In order to demonstrate that those requirements are met, wind power plant owners must conduct what are known as "validation tests" at their facilities. The Transmission Provider issues two types of documents covering the content of such tests:

1) The *General Validation Test Program* (this document), which is common to all wind power plants. It describes the validation tests to be performed at wind power plants regardless of the specific features of each. This document is available on the Transmission Provider's website.

2) The *Performance Field Tests Procedure* is specific to each wind power plant and contains the complete, individual series of validation tests for that generating facility. That procedure accounts for such things as wind power technology used, point of interconnection and requirements in effect at that specific plant. For local power system needs, the Transmission Provider may include additional tests to verify specific aspects not covered in the general test program. The procedure is submitted to the power producer at least two weeks prior to the date the wind power plant is first scheduled to go on line.

The first section of this document describes conditions for conducting validation tests. The second section describes the validation tests individually, broken down into seven modules.

DEFINITIONS

Low Voltage Ride Through
The ability of wind generators to remain in service during a voltage dip due to a fault.

Pnom
The nominal active power of a power plant or generating unit.

Telecontrol centre
Regional operating centre of the Transmission Provider.

Terminal voltage
The wind generator output voltage, i.e., the potential on the high-voltage terminals of the wind generator transformer (typically 34.5 kV).

1. Conducting validation tests

1.1 Purpose of testing

The Transmission Provider requires that tests be conducted for the following three purposes:

1. To demonstrate that the wind power plant meets Transmission Provider technical requirements related to wind generation
2. To validate numerical models and parameters associated with the wind power plant, specifically those given to the Transmission Provider by the power producer, by comparing model response to readings taken during the tests

Passing validation tests is a prerequisite for final Transmission Provider acceptance of wind power plant interconnection.

1.2 Validation test modules

Validation tests are broken down into seven modules, which verify the following:

- **Module A – Primary voltage regulation**
- **Module B – Undervoltage response (Low Voltage Ride Through)**
- **Module C – Inertial response (controlled by a frequency regulator)**[1]
- **Module D – Secondary voltage regulation**
- **Module E – Power factor**
- **Module F – Maximum ramp rates**
- **Module G –Power quality**

1.3 Time of testing

Validation testing must be performed immediately after the Distributor has agreed to commercial commissioning of the wind power plant.

Module A, B and C tests are performed on a single wind generator and may thus be run before all generators are in service.

Module D, E and F tests are performed on the wind power plant as a whole and are best run when all wind generators are in service with no restrictions on generation. To validate secondary voltage control (Module D), the voltage controller and/or any other equipment dedicated to that function (e.g., static or synchronous compensators) must be in service.

[1] This module only applies to wind power plants under call for tenders A/O 2005-03 (2,000 MW) and all subsequent wind power plants.

Module G validation is made once the wind power plant is in operation, using a monitoring system (see Section 1.6).

All testing must be coordinated with the Transmission Provider in the weeks and days prior to the tests and with the dispatcher at the telecontrol centre involved on the day of testing.

1.4 Power producer and Transmission Provider roles

The power producer has the obligation to perform validation testing in order to demonstrate that its facilities meet Transmission Provider requirements. At least three months in advance, it must inform the Transmission Provider of its intended timeframe for testing. The power producer must then promptly notify the Transmission Provider of any shift in timeframe.

The Transmission Provider will give the power producer the *Performance Field Tests Procedure* at least two weeks prior to the date that the wind power plant is first scheduled to go on line.

The power producer must let the Transmission Provider install instrumentation in its facilities to perform the tests and analyze the results, e.g., install a monitoring system at the point of interconnection or on the high-voltage bar of the switchyard, on a feeder and on a generating unit. The monitoring system may record signals either continuously or upon detecting that a disturbance-related threshold has been exceeded. 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 the fibre-optic cables and spare communication links that the Transmission Provider may use for tests or for ongoing monitoring (see Section 2 for records required for each test module). The power producer must, free of charge to the Transmission Provider, de-energize facilities as required for installing and disconnecting instrumentation.

The power producer must test one generating unit to verify that requirements during undervoltage conditions (Low Voltage Ride Through) are met, as described in document *Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Québec Transmission System*. If various types of wind generators (different technologies, settings or software versions) are used in the same wind power plant, a wind generator of each type must be tested.

The Transmission Provider will be present during the tests.

1.5 Certification

If the Transmission Provider deems that test results are conclusive, the wind power plant will be considered to meet Transmission Provider requirements for the (wind generator and wind power plant controller) software version verified at the time of testing. For the entire time the wind power plant is in operation, the power producer must notify the Transmission Provider if any new software version implemented and must document the changes made in that new version. The power producer must also notify the Transmission Provider of any change in voltage control at its facilities. In either case above, the Transmission Provider may require that validation tests be rerun in whole or in part at the expense of the power producer.

The Transmission Provider may waive the requirement to perform, in whole or in part, validation tests for wind power plants whose design, type of wind generator and controller software version have already passed the validation test program at a wind power plant integrated into its grid. Tests to confirm performance under transient undervoltage conditions (Low Voltage Ride Through) may likewise be waived if the power producer can produce a comprehensive report on tests performed on an identical generating unit (and with the same software version) demonstrating, to the Transmission Provider's satisfaction, that it meets Transmission Provider requirements.

1.6 Monitoring system

Certain parameters will be verified throughout the wind power plant's operation using a monitoring system installed by the Transmission Provider. This is the case for power quality requirements (module G). Such monitoring is also useful for other modules since only a limited number of operating conditions and disturbances can be verified by scheduled testing.

The monitoring system also enables the following requirements:

- Requirements during frequency variations
- Protection system requirements
- Requirements for wind generator shutdowns when very cold weather or high winds are forecast
- Requirements for stabilizer
- Requirements for limiting real power

1.7 Periodic testing

The Transmission Provider will make specific requests for periodic testing (about every five years). The power producer must, at its own expense, perform such tests and provide appropriate conditions for them, particularly for installing the instrumentation required. The Transmission Provider will supply the test procedure and may assist the power producer in performing the tests, if necessary. Such tests will follow a similar procedure as for the initial tests so that results can be compared.

2. Description of validation tests

2.1 Module A – Primary voltage regulation

Primary voltage regulation is achieved using a control loop located at the wind generator. Generally, it is the dynamic response of the control loop that characterizes instantaneous (transient) voltage control for the wind power plant. The tests below apply to this general situation where reactive power for voltage regulation comes uniquely from the wind generators. If transient voltage control is ensured by adding other equipment to the power plant (e.g., compensators), however, a specific test procedure will be developed to assess the transient response of such equipment and to determine whether or not requirements are met.

Purpose

These tests are designed to measure the local dynamic response of a wind generator to a rapid voltage change and to verify that the response meets voltage regulation requirements.

Requirements

The result of these tests must show that the wind power plant meets the specifications described at section *Requirements regarding voltage regulation and power factor* of document *Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Québec Transmission System.*

Description of tests

The tests are performed on a single wind generator. The generator must be isolated from any secondary voltage control system. For each test, wind generator output must exceed 50% of its rated capacity.

Part 1 tests consist in producing instantaneous voltage variations of low amplitude on the high-voltage side of the wind generator (terminal voltage). If there is a test facility isolating the wind generator through an impedance and enabling its terminal voltage to be controlled, that facility will produce the voltage variations. If not, the voltage variations will be generated by switching operations on the power system (switching capacitor banks, reactors, etc.) or by changing the position of switchyard power transformer taps.

Part 2 tests consist in injecting small voltage steps of limited duration directly into the wind generator voltage control system. Such tests are only feasible if the generator has a voltage control system that is accessible.

Module A tests

Part 1

Test A1.1 Instantaneous rise in terminal voltage of about 1% to 2%

Test A1.2 Instantaneous fall in terminal voltage of about 1% to 2%

Test A1.3 Instantaneous rise in terminal voltage of about 3% to 5%

Test A1.4 Instantaneous fall in terminal voltage of about 3% to 5%

Part 2

Test A2.1 Positive voltage step of about 2% lasting from 0.5 to a few seconds

Test A2.2 Negative voltage step of about 2% lasting from 0.5 to a few seconds

Test A2.3 Positive voltage step of about 5% lasting from 0.5 to a few seconds

Test A2.4 Negative voltage step of about 5% lasting from 0.5 to a few seconds

Measurements recorded

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

- Voltages of the three phases on the low-voltage side
- Currents of the three phases on the low-voltage side

2.2 Module B – Undervoltage response (Low Voltage Ride Through)

Requirements during undervoltage conditions (Low Voltage Ride Through) stipulate that wind generators must remain in service during voltage disturbances. The tests below are performed on a wind generator. It is thus assumed that each wind generator meets these requirements independently. In instances where requirements are met by adding other equipment to the power plant (e.g., compensators), a specific test procedure will be established.

Purpose

These tests are designed to verify that wind generators meet requirements during undervoltage conditions (Low Voltage Ride Through) and to measure generator response during severe voltage disturbances.

Requirements

The result of these tests must show that the wind power plant meets the specifications described at section *Requirements during undervoltage conditions (Low Voltage Ride Through)* of document *Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Québec Transmission System.*

Description of tests

Tests are performed on a single wind generator. A first series of tests is performed with the wind generator output at 100% of its rated capacity. A second series of tests is performed with the wind generator output at about 20% of its rated capacity. The voltage dips durations specified in cycles are based on a 60 Hz frequency system. For example, "9 cycles" corresponds to 0.15 seconds.

These tests require a test facility isolating the wind generator through an impedance and allowing different values of voltage dips on the high-voltage side of the wind generator transformer's (such as shown in the standard IEC 61400-21). The voltage dips described below in stages B1 to B18 reflect the requirements of TransÉnergie which are specified on the high-voltage side of the switchyard. To simplify the tests procedure, we demand to apply these voltage dips on the high-voltage side of the wind generator transformer's. If not possible, the voltage dips applied on the high-voltage side of the wind generator transformer's could be computed considering the impedance and connection mode of the high-voltage transformer(s) of the switchyard. These voltage dips would then have to correspond to the conditions on the high-voltage side of the closest wind generator transformer's, when the voltage conditions described in the stages B1 to B18 are effective on the high-voltage side of the switchyard.

Module B tests

Test B1 Voltage dip on three phases giving a remaining positive-sequence voltage of 0.95 p.u., for 1 hour.

Test B2 Voltage dip on one phase giving a remaining positive-sequence voltage of 0.90 p.u., for 10 minutes.

Test B3 Voltage dip on two phases giving a remaining positive-sequence voltage of 0.90 p.u., for 10 minutes.

Test B4 Voltage dip on three phases, giving a remaining positive-sequence voltage of 0.90 p.u , for 10 minutes.

Test B5 Voltage dip on one phase giving a remaining positive-sequence voltage of 0.85 p.u., for 30 seconds.

Test B6 Voltage dip on two phases giving a remaining positive-sequence voltage of 0.85 p.u., for 30 seconds.

Test B7 Voltage dip on three phases giving a remaining positive-sequence voltage of 0.85 p.u., for 30 seconds.

Test B8 Voltage dip on one phase giving a remaining positive-sequence voltage of 0.75 p.u., for 2 seconds.

Test B9 Voltage dip on two phases giving a remaining positive-sequence voltage of 0.75 p.u., for 2 seconds.

Test B10 Voltage dip on three phases giving a remaining positive-sequence voltage of 0.75 p.u., for 2 seconds.

Test B11 Three-phase fault, lasting 9 cycles.

Test B12 Phase-to-phase fault, lasting 9 cycles.

Test B13 Two-phase-to-ground fault, lasting 9 cycles.

Test B14 Single-phase-to-ground fault, lasting 15 cycles or 18 cycles (depending on requirements in force).

Test B15 Three-phase fault with impedance giving a remaining positive-sequence voltage of 0.25 p.u., lasting 45 cycles.

Test B16 Two-phase-to-ground fault with impedance giving a remaining positive-sequence voltage of 0.50 p.u., lasting 45 cycles.

Test B17 Phase-to-phase fault with impedance giving a remaining positive-sequence voltage of 0.60 p.u., lasting 45 cycles.

Test B18[2] Single-phase fault with impedance giving a remaining positive-sequence voltage of 0.70 p.u., lasting 45 cycles.

Measurements recorded

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

- Voltages of the three phases on the high-voltage side
- Currents of the three phases on the high-voltage side
- Voltages of the three phases on the low-voltage side
- Currents of the three phases on the low-voltage side
- Rotor speed

[2] This test only applies to wind power plants for which requirements in force specify a remote single-phase fault cleared by a slow protective device

2.3 Module C – Inertial response

Note: This module only applies to wind power plants under call for tenders A/O 2005-03 (2,000 MW) and all subsequent wind power plants.

Purpose

These tests are designed to verify that wind generators meet requirements regarding frequency control (inertial response).

Requirements

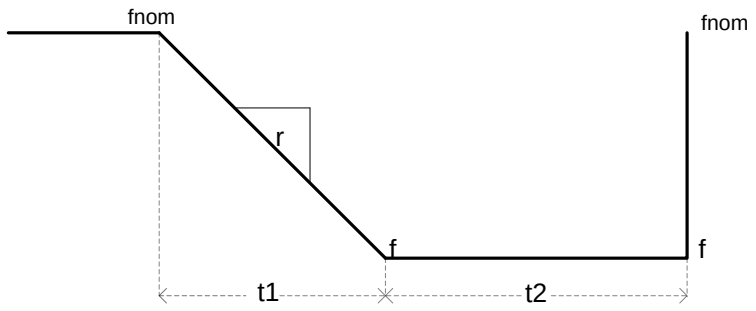
The result of these tests must show that the wind power plant meets the specifications described at section *Frequency control requirements* of document *Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Québec Transmission System.*

Description of tests

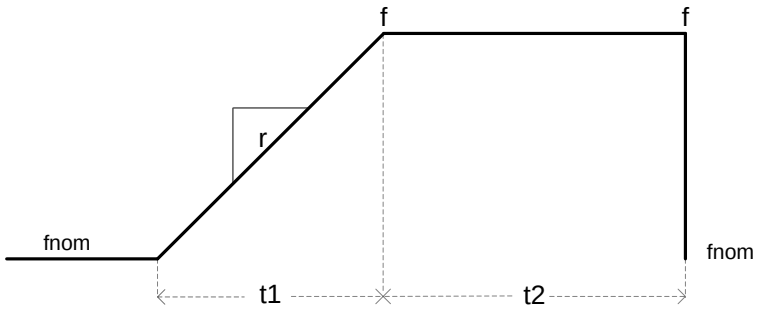
The tests are performed on a single wind generator. The wind generator output must be between 5% and 100% of its rated capacity, depending of the test. During the test, the wind generator output has to reflect the wind condition`s which means that no curtailment or power restriction must be applied to the wind generator.

Tests consist in applying frequency signals of limited duration directly to the wind generator frequency control system. The frequency signals have the following profile:

For Part 1 tests



For Part 2 tests



The values of parameters ***f***, ***t1***, ***t2*** and ***r*** are defined for each test. Those values are given in rough way in the next section. They will be specified in the test procedures where they will adapted to the settings and technologies of the tested frequency control system.

In order to appreciate the effect of the pitch control on the inertia response (recovery phase), test C1.8 will be performed in wind conditions where the pitch is above its minimum.

Module C tests

Part 1

Test C1.1 f = 59 Hz, t1 = 20 seconds, t2 =15 seconds, r = 0.05 Hz/second
Output between 30% and 90% of the rated capacity of the wind generator.

Test C1.2 f = 59.6 Hz, t1 = 4 seconds, t2 =2 seconds, r = 0.10 Hz/second
Output between 30% and 90% of the rated capacity of the wind generator.

Test C1.3 f = 59 Hz, t1 = 10 seconds, t2 =10 seconds, r = 0.10 Hz/second
Output between 30% and 90% of the rated capacity of the wind generator.

Test C1.4 f = 58.5 Hz, t1 = 10 seconds, t2 =10 seconds, r = 0.15 Hz/second
Output between 30% and 90% of the rated capacity of the wind generator.

Test C1.5 f = 59 Hz, t1 = 10 seconds, t2 =35 seconds, r = 0.10 Hz/second
Output between 30% and 90% of the rated capacity of the wind generator.

Test C1.6 f = 59 Hz, t1 = 10 seconds, t2 =35 seconds, r = 0.10 Hz/second
Output between 5% and 10% of the rated capacity of the wind generator.

Test C1.7 f = 59 Hz, t1 = 10 seconds, t2 =35 seconds, r = 0.10 Hz/second
Output of 100% of the rated capacity of the wind generator.
Pitch at its minimum.

Test C1.8 f = 59 Hz, t1 = 10 seconds, t2 =35 seconds, r = 0.10 Hz/second
Output of 100% of the rated capacity of the wind generator.
Pitch above its minimum value.

Part 2

Test C2.1 f = 60.35 Hz, t1 = 7 seconds, t2 =20 seconds, r = 0.05 Hz/second
Output between 30% and 90% of the rated capacity of the wind generator.

Test C2.2 f = 60.8 Hz, t1 = 16 seconds, t2 =20 seconds, r = 0.05 Hz/second
Output between 30% and 90% of the rated capacity of the wind generator.

Test C2.3 f = 61.0 Hz, t1 = 10 seconds, t2 =20 seconds, r = 0.1 Hz/second
Output between 30% and 90% of the rated capacity of the wind generator.

Test C2.4 f = 61.2 Hz, t1 = 6 seconds, t2 =20 seconds, r = 0.2 Hz/second
Output between 30% and 90% of the rated capacity of the wind generator.

Measurements recorded

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

- Voltages of the three phases on the low-voltage side
- Currents of the three phases on the low-voltage side
- Rotor speed
- Blade pitch
- Input and output signals of the frequency control system
- Wind speed

2.4 Module D – Secondary voltage regulation

When implemented, secondary voltage regulation may judiciously complement primary regulation. In particular, it can allow continuous voltage control on the high-voltage side of power producer facilities (or at the point of interconnection). The tests below apply when the secondary voltage regulation loop is managed by a system we shall call a "voltage controller", which controls wind generator reactive power based on a voltage set point on the high-voltage side of the switchyard. The tests thus apply to the general case where reactive power originates uniquely from the wind generators. If voltage control is ensured by adding other equipment to the power plant (e.g., compensators), a specific test procedure will be developed to assess the response of such equipment and to determine whether or not requirements are met.

Purpose

These tests are designed to measure the response of the secondary voltage regulation system and to verify that, complementing primary voltage regulation, it enables voltage regulation requirements to be met.

The tests are also used to verify how the regulation works with a permanent droop, if that option exists.

Lastly, the tests are a means of verifying reactive power dynamics at the power plant when the voltage controller is turned on and off.

Requirements

The result of these tests must show that the wind power plant meets the specifications described at section *Requirements regarding voltage regulation and power factor* of document *Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Québec Transmission System.*

Description of tests

Tests are performed with at least 95% of the wind generators in service and power plant output exceeding 50% of its rated capacity.

Part 1 tests consist in applying low-amplitude voltage variations on the grid, generated by switching operations there (switching capacitor banks, reactors, tap positions, etc.).

Part 2 tests consist in applying set point steps to the voltage controller.

Part 3 test consists in turning off the voltage controller and, once reactive power has stabilized, turning it back on.

Part 1 and Part 2 tests are first run with no permanent droop. They are then rerun with permanent droop values ranging from 2% to 8%. These tests may require changes to voltage controller settings (gain values, time constants, etc.).

The Part 3 test is only run with no permanent droop.

Module D tests

Part 1

Test D1.1 Rise in grid voltage of about 1%

Test D1.2 Fall in grid voltage of about 1%

Test D1.3 Rise in grid voltage of about 3%

Test D1.4 Fall in grid voltage of about 3%

Test D1.5 Fall in grid voltage of about 3% followed by a rise of about 5% a few seconds later

Part 2

Test D2.1 Positive voltage set point step of about 1% to 2%

Test D2.2 Negative voltage set point step of about 1% to 2%

Test D2.3 Positive voltage set point step of about 3% to 5%

Test D2.4 Negative voltage set point step of about 3% to 5%

Test D2.5 Negative voltage set point step of about 3% to 5% followed by a positive set point step of 2% a few seconds later

Run Part 1 and Part 2 tests with no permanent speed droop. Next rerun them with two different permanent speed droop values (between 2% and 8%).

Part 3

Test D3 Turn off the voltage controller until the wind generator output stabilizes. Next turn the voltage controller back on.

Measurements recorded

The following signals are to be recorded at one wind generator:

- Voltages of the three phases on the low-voltage side
- Currents of the three phases on the low-voltage side
- Rotor speed
- Blade pitch
- Wind speed

The following signals are to be recorded at the feeder (near the switchyard) of one of the collector system lines:

- Voltages of the three phases
- Currents of the three phases

The following signals are to be recorded on the high-voltage side of the switchyard:

- Voltages of the three phases
- Currents of the three phases

2.5 Module E – Power factor

The tests below consider the general case where reactive power originates uniquely from the wind generators. In instances where power factor requirements are met by adding equipment to the power plant (e.g., compensators), a specific test procedure will be developed to determine whether or not requirements are met.

Purpose

These tests are designed to verify that the power plant meets power factor requirements and to measure the maximum reactive power capacity of the power plant and of a wind generator.

Requirements

The result of these tests must show that the wind power plant meets the specifications described at section *Requirements regarding voltage regulation and power factor* of document *Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Québec Transmission System.*

Description of tests

Tests must ideally be run with all wind power plant generators in service. Depending on the test, the output of the wind generators in service ranges from 10% to 100% of their rated capacity. In certain cases, TransÉnergie may agree that tests be run with a smaller number of wind generators in service and that results be extrapolated to compute the maximum reactive power that the power plant supplies (or absorbs). Voltage restrictions on the local system may also entail running tests with a limited number of wind generators.

Tests consist in supplying and absorbing a maximum amount of reactive power at different levels of output and with a voltage range between 0.90 p.u. and 1.10 p.u. on the high-voltage side of the switchyard.

Tests may require changing the set points of the voltage control system(s).

Module E tests

Test E1 Wind generators output at 100% of their rated capacity, maximum capacitive reactive power, during 1 hour

Test E2 Wind generators output at 100% of their rated capacity, maximum inductive reactive power, during 1 hour

Test E3 Wind generators at 50% of their rated capacity, maximum capacitive reactive power, during 5 minutes

Test E4 Wind generators at 10% of their rated capacity, maximum inductive reactive power, during 5 minutes

Measurements recorded

The following signals are to be recorded at one wind generator:

- Voltages of the three phases on the low-voltage side
- Currents of the three phases on the low-voltage side

The following signals are to be recorded at the feeder (near the switchyard) of one of the collector system lines:

- Voltages of the three phases
- Currents of the three phases

The following signals are to be recorded on the high-voltage side of the switchyard:

- Voltages of the three phases
- Currents of the three phases

2.6 Module F – Maximum ramp rates

Purpose

These tests are designed to verify that requirements relating to maximum ramp rates are met when the power plant is being started or shutdown with a ramp rate control device.

Requirements

The result of these tests must show that the wind power plant meets the specifications described at section *Requirements for maximum up-and down-ramp rates* of document *Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Québec Transmission System.*

Description of tests

Tests must be run with at least 95% of wind power plant generators in service. The output of the wind generators in service must exceed 50% of their rated capacity.

Testing consists in performing a power plant shutdown sequence and then a startup sequence and observing whether the applicable ramp rates are met.

These tests may require changes to power controller settings for the wind power plant or wind generators.

Module F tests

Test F1 Ramp rate adjusted to Pnom/10 minutes, complete power plant shutdown

Test F2 Ramp rate adjusted to Pnom/10 minutes, power plant startup

Test F3 Ramp rate adjusted to Pnom/60 minutes, complete power plant shutdown

Test F4 Ramp rate adjusted to Pnom/60 minutes, power plant startup

Measurements recorded

The following signals are to be recorded at one wind generator:

- Voltages of the three phases on the low-voltage side
- Currents of the three phases on the low-voltage side
- Rotor speed
- Blade pitch
- Wind speed

The following signals are to be recorded at the feeder (near the switchyard) of one of the collector system lines:

- Voltages of the three phases
- Currents of the three phases

The following signals are to be recorded on the high-voltage side of the switchyard:

- Voltages of the three phases
- Currents of the three phases

2.7 Module G – Power quality

Scheduled testing will not cover power quality requirements. Harmonics and emission limits will instead be verified during wind power plant operation by means of a monitoring system installed by the Transmission Provider (see Section 1.6). This will ensure compliance with standards such as those set out by the power producer in the report *Emission study.* This report is a prerequisite for initial energization of the wind power plant.