Hydro Québec TransÉnergie

TRANSMISSION PROVIDER TECHNICAL REQUIREMENTS FOR THE CONNECTION OF POWER PLANTS TO THE HYDRO-QUÉBEC TRANSMISSION SYSTEM

Direction Planification des actifs

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These Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Québec Transmission System were translated into English by Hydro-Quebec. In the event of a conflict between the French text and the English text, the French text shall prevail.

Table of Contents

List of Figures

List of Tables

1. PURPOSE AND APPLICATION

1.1 Purpose

This document sets out the *transmission provider*’s minimum technical requirements for connecting *power plants* to the Hydro-Québec *transmission system*. The *power plants* may be connected either directly to the *transmission system* or through *facilities* not owned by the *transmission provider*. As set out in Section 1.2, these requirements apply to new *power plants* and to existing *power plants* undergoing *modifications*.

The requirements in this document are primarily intended to ensure efficient operation of the Hydro-Québec *transmission system* based on five factors:

- Reliability of the Hydro-Québec *transmission system*
- Stability of the *transmission system* and of the *power plants* connected to it
- Consistent high-quality service for customers connected to the Hydro-Québec *transmission system*
- Protection of Hydro-Québec equipment
- Safety of Hydro-Québec employees

This document is not to be construed as the sole source of technical specifications for designing the *power producer facilities*. *Power producer* equipment and *facilities* must also comply with codes, standards and rules applicable in Québec, and to *good utility practice*.

Stipulations in the Hydro-Québec Open Access Transmission Tariff also apply to all *power plants* connected to the Hydro-Québec *transmission system*.

Appendices A, B, C and D of this document are an integral part of the technical requirements for the connection of *power plants*.

1.2 Application

Note: The requirements in this document also apply to wind plants. A number of supplementary technical requirements, however, have been laid down to cover certain technical aspects specific to wind generation. Section 14 contains those requirements.

A All requirements in this document apply to the connection of *power plants* to the *transmission system* in any of the situations below.

A-1 A new *power plant* connected directly to the Hydro-Québec *transmission system*, except for the emerging generating options under B-4.

A-2 A new *power plant* connected through the *facilities* of an *industrial customer*, in which case other requirements also apply to the *facilities* of that customer as set out in the document Technical Requirements for Customer Facilities Connected to the Hydro-Québec Transmission System or to any later version thereof.

A-3 *Modifications* to an existing *power plant* already connected directly or through *industrial customer facilities*. These requirements then apply to the equipment or *facilities* undergoing the *modifications.* Any *modification* of an existing *power plant* must be approved by the *transmission provider*.

B A number of requirements in this document apply to the connection of new *power plants* or to *modification* of an existing *power plant* already connected to the *transmission system* in any of the situations below.

B-1 A *power plant* connected to the distribution system. Requirements having an impact on the *transmission system* then apply, namely:

- the frequency control requirements in Section 5.3.3
- the requirements governing frequency ranges and the minimum time *power plants* must remain in service without *generating unit tripping*, as specified in Section 4.2.2.1, Table 2
- the *Power plant remote tripping* requirements in Section 7.4.3.3
- certain requirements regarding information needed by the telecontrol centres (TCs) and the System Control Centre (SCC) given in Section 8.3; more specifically, measurements of injected real and reactive power.

Further d*istributor*-specified requirements apply to *power plants* connected to the distribution system.

B-2 A *power plant* connected to the *facilities* of a *neighboring system within Québec*. The requirements set down by the owners of that system then apply. In addition, as coordinator for the Québec control area, the *transmission provider* minimally requires that *power plants* connected to the *neighboring system within Québec* meet the following requirements in this document:

- the requirements on maximum loss of generation following a single-element contingency in Section 4.2.1
- the requirements in Section 4.2.2.1, Table 2 governing frequency ranges and the minimum time *power plants* must remain in service without *generating unit tripping*
- the frequency control requirements in Section 5.3.3.

In addition to the above, the owners of the *neighboring system within Québec* are strongly recommended to incorporate Section 5.3.2 requirements on static excitation systems into their own requirements.

B-3 A *power plant* connected to a *municipal system* or the *SJBR electricity cooperative*. The same principles apply as those stated for a *power plant* connected to *facilities* of a *neighboring system within Québec*.

B-4 Various emerging generating options like fuel cells and photovoltaic cells. Such technology is now marginal in Québec. Most requirements in this document apply to such technology, particularly the requirements governing frequency ranges and the minimum time *power plants* must remain in service without *generating unit tripping*, as specified in Section 4.2.2.1, Table 2. Specific studies and technical requirements will also cover such generating options due to the impacts they may have on the *transmission system*.

Given technology trends, progress in connection methods and possible future system constraints, the *transmission provider* may introduce further requirements based on studies it conducts.

This document does not cover *generating facilities* to be connected to a Hydro-Québec *off-grid system*.

2. Definitions

Italicized terms in the text are defined below.

Asynchronous generator

An asynchronous machine operating to generate electricity. It may be connected to the grid directly or through a converter.

Bulk power system

(*NPCC* definition) The interconnected electrical system in northeastern North America comprising generation and transmission *facilities* on which faults or *disturbances* can have a significant adverse impact outside of the local area (local areas being determined by NPCC members).

In line with this definition, Hydro-Québec has a document describing the method it applies to identify its *bulk power system*, entitled “Les Critères de Conception du Réseau de Transport Principal”. The method generally consists in finding power system components for which a three-phase fault not cleared by the local protection system would result in a “significant adverse impact”, meaning:

- instability of the Hydro-Québec *transmission system*
- an unacceptable dynamic response on the grid (e.g., a major loss of load or generation) or *tripping* of equipment leading system frequency to deviate beyond the allowable range (i.e., lower than 58.5 Hz or higher than 61.7 Hz)
- a voltage level exceeding emergency limits in effect outside the local area
- a level of load on transmission equipment exceeding emergency limits in effect outside the local area
- any event producing an unacceptable effect on a bulk power facility of a neighboring system

The *bulk power system* is subject to stricter design, operation and maintenance standards, as borne out by *NPCC* documents.

Connection switch

The first visible disconnection point (disconnecting switch) in the *power producer facilities* closest to the *point of interconnection*.

Distributor

Hydro-Québec when carrying on electric power distribution activities.

Disturbance

A departure from the normal operating conditions of a power system. In this document, the term generally designates departures resulting from sudden, random, fortuitous events (e.g., faults, inadvertent operation of a special or conventional protection system, or loss of generation or load). In other instances, the departure may be more or less periodical and of lesser magnitude (e.g., harmonics, flicker, switching surges, or power oscillations due to an inappropriate setting or to a regulation system failure).

Facilities study

An engineering study conducted by the *transmission provider* after the *interconnection study* to determine the *network upgrades* required to connect a *power plant*, their cost and the projected completion date.

Facility

A set of equipment and/or conductors, such as *generating units*, transformers, synchronous or static compensators, substations and lines, taken alone or as a whole. This also includes station services, cooling systems, control, monitoring and protection equipment, etc.

Generating unit

A unit that produces electricity, usually comprised of a synchronous turbine-generator combination (synchronous *generating unit*) or an asynchronous turbine-generator combination (asynchronous *generating unit*).

Generating unit circuit breaker

The circuit breaker closest to a *generating unit*.

Good utility practice

Any of the practices, methods and acts engaged in or approved by a significant portion of the electric utility industry during the relevant time period, or any of the practices, methods and acts which, in the exercise of reasonable judgment in light of the facts known at the time the decision was made, could have been expected to accomplish the desired result at a reasonable cost consistent with good business practices, reliability, safety and expedition. *Good utility practice* is not intended to be limited to the optimum practice, method or act to the exclusion of all others, but rather to be practices, methods or acts generally accepted in the region.

Interconnection study

An evaluation by the *transmission provider* of the adequacy of the Hydro-Québec *transmission system* to accommodate a request to connect a *power plant* and of *network upgrades* possibly needed to do so.

Industrial customer

In this document, any end-use customer connected to the Hydro-Québec *transmission system* (which excludes customers connected through a *neighboring system within Québec*, a *municipal system*, or the *SJBR electricity cooperative*).

Islanding

The splitting of a power system into subsystems with both a load or electrical equipment and generating *facilities*. This phenomenon generally arises following a *disturbance* or a switching operation.

Major load centre

Québec's major load centres are roughly found within the geographic area labelled CENTRAL QUÉBEC on the TransÉnergie map on page 9.

Modification

Any changes besides normal maintenance made at an existing *power plant* to overhaul or replace outdated *facilities* or equipment, or which result in changing the services provided, or electrical or mechanical characteristics, such as rated power, maximum power, control and protection systems, or station services, or in changing software (or software versions) for *facilities* using power electronics, etc.

Municipal system and *SJBR electricity cooperative*

Under the Act respecting the Régie de l'énergie, the municipal power distribution systems governed by the Act Respecting Municipal and Private Electric Power Systems (R.S.Q. c.S-41), including the Coopérative régionale d'électricité de Saint-Jean-Baptiste-de-Rouville (*SJBR electricity cooperative*), which have been the *distributor*'s customers since May 13, 1997.

Neighboring system within Québec

A power system in Québec that is not owned by Hydro-Québec and that is interconnected synchronously to the Hydro-Québec *transmission system*.

NERC (North American Electric Reliability Council) [1]

An organization mandated to promote the reliability of electricity service in North America. It comprises ten regional reliability councils that cover virtually all the electricity supplied in the U.S., Canada, and a portion of Baja California Norte, Mexico.

Network upgrade

Any modification or addition to transmission facilities incorporated into the *transmission provider*'s *transmission system* in response to a request for the connection or *modification* of a *power plant*.

NPCC (Northeast Power Coordinating Council) [2]

A voluntary coalition of electric power stakeholders working in northeastern North America. The organization is a *NERC* regional reliability council whose membership includes several electric utilities and independent system operators active in five regions, called "control areas": New York State, New England, Québec, Ontario and the Maritime Provinces.

Off-grid system

A power system permanently unconnected to the integrated Hydro-Québec *transmission system*.

Point of interconnection

In this document, any boundary point between the Hydro-Québec *transmission system* and the electrical *facilities* of a *power producer*.

Power plant

A site where electricity is produced and which may include a *switchyard* or part thereof. In this document, *power plant* denotes all *power producer facilities* located at a given generating site (e.g., a hydroelectric, thermal or wind *power plant*), and also includes any *industrial customer facilities* used to connect the *power plant*.

Power producer

Any person or entity, including Hydro-Québec, when carrying on electric power generation activities.

1 Web site: http://www.nerc.com
2 Web site: htpp://www.npcc.org

Remote tripping

The opening of a circuit breaker actuated at a distance by a special protection system.

Satellite substation

The *transmission system* substation that supplies a distribution system. In most cases, it is a transformer substation that steps down high voltages (HV) to medium voltages (MV), usually 12 kV or 25 kV.

Switchyard

The substation through which *power producer facilities* are connected to the *transmission system*. It is generally the transformer substation close to the *power plant*. The *switchyard* comprises the high-voltage portion of the substation and extends through the step-up transformers to their low-voltage terminals. If multiple voltage steps are required at the *switchyard*, they are also included. In this document, if the *power plant* is connected to the *transmission system* through the *facilities* of an *industrial customer*, that customer's substation is considered to be the *switchyard*.

Synchronous generator

A synchronous machine operating to generate electricity. It may be connected to the grid directly or through a converter.

Tie breaker(s)

The circuit breaker(s) located closest to the *connection switch*. Such breakers isolate *power producer facilities* from the *transmission system* under fault conditions.

Transmission provider

Hydro-Québec when carrying on electric power transmission activities.

Transmission system

The set of *facilities* for carrying electricity, including step-up transformers on generating sites, transmission lines rated 44 kV and over, transmission substations and any other *facility* for connecting generating sites to the distribution system.

Tripping/reclosing

The change in state of a circuit breaker brought about by a special or conventional protection system.


Détroit d'Hudson
Baie d'Hudson
Baie d'Ungava
Mer du Labrador
Québec
Labrador (Terre-Neuve)
Baie James
Radisson
Chisasibi
La Grande-4
Laforge-1
Churchill Falls (Terre-Neuve)
Montagnais
Nemiscau
Albanel
Abitibi
Chibougamau
Matagami
Rouyn-Noranda
Manic-5-PA
Manic-5
Sainte-Marguerite-3
Arnaud
Sept-Îles
Outardes-4
Manic-3
Manic-2
Outardes-3
Bersimis-1
Bersimis-2
Baie-Comeau
Chicoutimi
Chamouchouane
Saguenay
Fleuve Saint-Laurent
Rimouski
Golfe du Saint-Laurent
Terre-Neuve
La Vérendrye
Québec
Gentilly-2
Appalaches
Grand-Brûlé
Tracy
Montréal
Des Cantons
Ontario
Ottawa
CANADA
CENTRAL QUEBEC
For a detailed map see :
http://www.hydro.qc.ca/transenergie/en/commerce/producteurs_prives.html
DIRECTION PLANIFICATION DES ACTIFS
UNITÉ PROGRAMME ET STRATÉGIES DU RÉSEAU PRINCIPAL
Hydro-Québec
TransÉnergie
DESSINÉ
PROJETÉ
APPROUVÉ
APPROUVÉ
R. DE T.
DATE
ÉCHELLE
0 50 150 km
SOURCE: Un mode d'énergie
UNITÉ GÉOMATIQUE
CARTE GÉOGRAPHIQUE
LOCALISATION DES GRANDS CENTRES DE CHARGE
(CENTRE DU QUÉBEC)
APPROUVÉ
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G240 20260 080 01 0PL 4

3. Connection and Studies Required

3.1 Connection

3.1.1 Determining the connection solution for the *power plant*

The *transmission provider* chooses the solution for connecting the *power plant* to the *transmission system* and determines what *network upgrades* this entails by conducting the studies given in Section 3.2.

The solution is chosen based on technical and economic criteria to optimize use of the *transmission system*, while being environmentally acceptable.

3.1.2 *Point of interconnection*

As defined in Section 2, the *point of interconnection* is the boundary point between the Hydro-Québec *transmission system* and the electrical *facilities* of the *power producer*.

Power producer facilities must have a visible disconnection point so they can be disconnected from the *transmission system* for grid operation purposes. As indicated in Section 6.3, the *power producer* generally achieves this using a *connection switch* that it installs at each *point of interconnection*. These *connection switches* must be accessible at all times so the *transmission provider* can lock them out.

One or more *tie breakers* (see Section 6.5.1) are required in the *switchyard*. The number depends, for instance, on whether there are several step-up transformers (see Section 6.9) connecting the *power plant* to the *transmission system*, in which case several *tie breakers* may be required to meet *transmission system* requirements.

When the *point of interconnection* is on the high-voltage side of the *switchyard*, one *tie breaker* (or more depending on the configuration) is required on that side. The breaker must be located between the *switchyard*'s step-up transformer and the *connection switch* and as close as possible to the latter. Voltage and current transformers (see Section 7.5.4) must be located on the high-voltage side of the *switchyard* between the *connection switch* and *tie breaker* unless another arrangement has been specifically agreed to with the *transmission provider*. This rule also applies to surge arresters (see Section 6.4) if the *power producer* wants to install any on the high-voltage side of the *switchyard*.

If the *point of interconnection* is located on the low-voltage side of the *switchyard*, one or more *tie breakers* (depending on the configuration) may be required on either the high- or low-voltage side of the step-up transformer(s) used to connect the *power plant*.

The figures in Sections 3.1.2.1 and 3.1.2.2 show roughly the position relative to the *point of interconnection* of certain devices to which specific requirements herein apply. The figures in parentheses give the section dealing with each device. Note that the diagrams do not necessarily depict all required *switchyard* equipment and devices.

3.1.2.1 *Power plants* not owned by Hydro-Québec

Figures 1 and 2 show the two most common types of connection used for a *power plant* that is not Hydro-Québec property.

Figure 1 shows a *power plant* connected directly to the *transmission system*. In this case, the *point of interconnection* is generally located on the high-voltage side of the *power producer*'s *switchyard*.

Figure 1 – *Power plant* connected directly to the *transmission system*

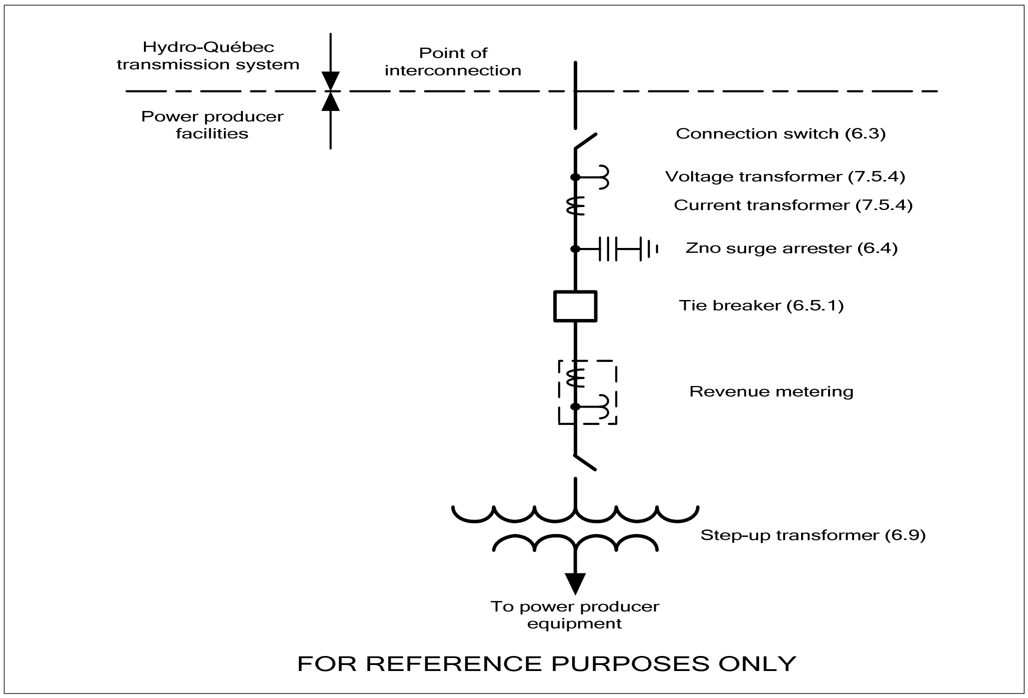
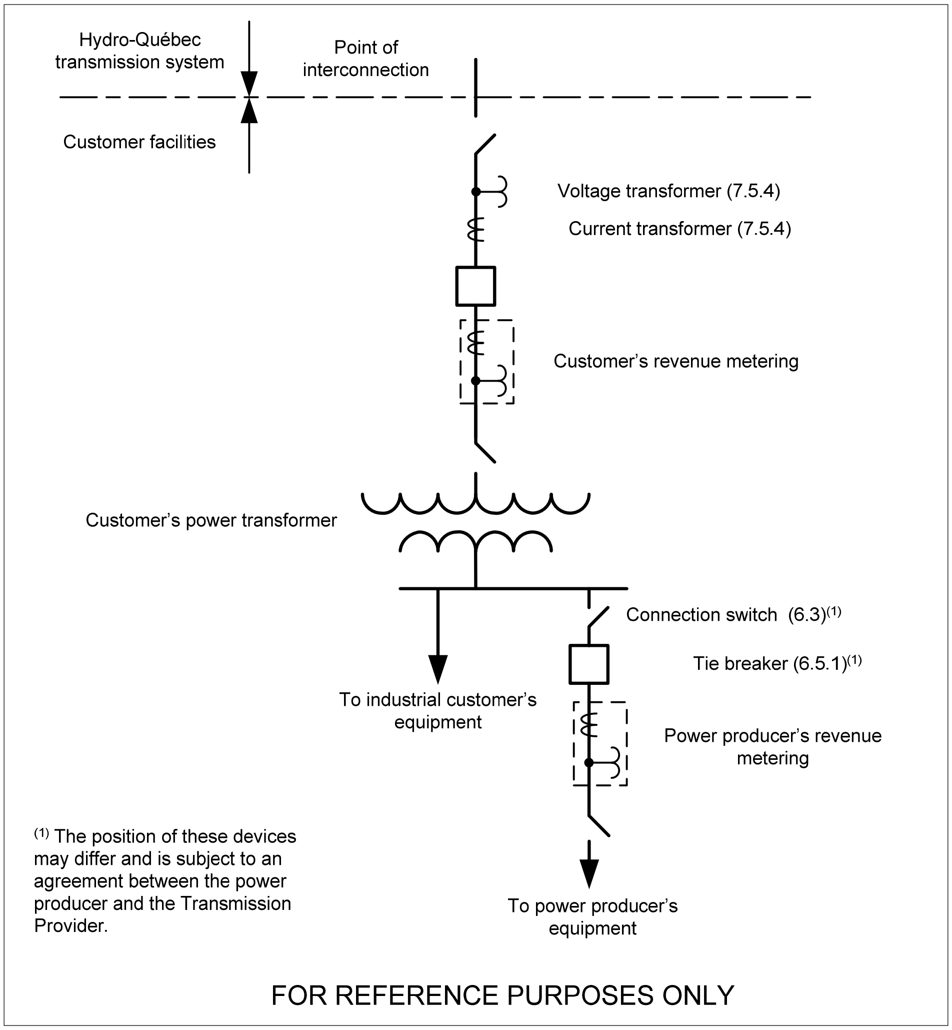


Figure 2 shows a *power plant* connected to the *transmission system* through the *facilities* of an *industrial customer*. In this case, the *point of interconnection* is generally located on the high-voltage side of the customer's transformer substation. For the purposes of this document, the customer substation is considered as being the *switchyard*.

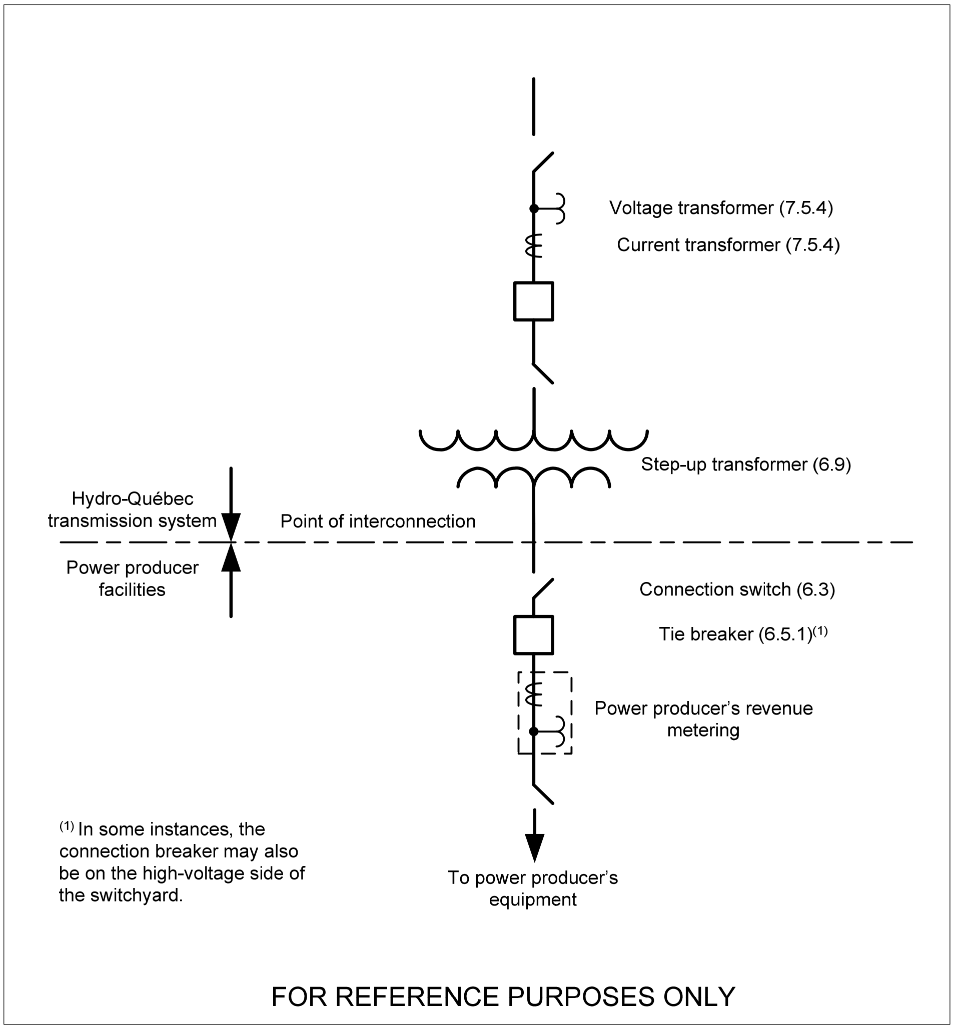
Figure 2 – *Power plant* connected through *industrial customer facilities*



3.1.2.2 *Power plants* owned by *Hydro-Québec*

Figure 3 shows a *power plant* that is Hydro-Québec property. In this case, the *point of interconnection* is located on the low-voltage side of the *switchyard*.

Figure 3 – *Power plant* owned by Hydro-Québec



3.2 Studies required

It is up to the *transmission provider* to determine whether *network upgrades* are required for a *power plant* to be connected to the *transmission system*. The *transmission provider* must also ensure that connecting a new *power plant* to the *transmission system* will neither compromise nor unduly reduce the quality and reliability of service to customers connected to the Hydro-Québec *transmission system* and will not reduce transmission capacity to the point of preventing the *transmission provider* from honoring its contractual commitments. The studies described below make it possible to verify this. The *transmission provider* conducts the *interconnection study* and *facilities study*, while the *power producer* conducts the protection study for its own *facilities*.

3.2.1 *Power producer* responsibility regarding technical information to submit to the *transmission provider*

The *power producer* must submit the information listed in Appendix A herein to the *transmission provider* so the latter can begin the studies required to assess the impact of connecting the *power plant* and to determine whether *network upgrades* are needed. For a wind *power plant*, it must also submit the information listed in Appendix B.

The *power producer* is responsible for the validity of information (data, models and associated parameters), whether submitted to the *transmission provider* by the *power producer* itself or by its supplier. If *power producer facilities* do not behave according to the models and parameters submitted, the *transmission provider* will if necessary re-evaluate the cost of connecting the *power plant* to the *transmission system*.

3.2.2 *Interconnection study*

For every project to add a *power plant* to the Hydro-Québec *transmission system* and for some projects to modify an existing *power plant*, the *transmission provider* carries out an *interconnection study* to determine what *network upgrades* are required to connect the *power plant*.

The *transmission provider* conducts the *interconnection study* based on:

- *good utility practice*
- *NPCC* and *NERC* criteria and guidelines, and
- Hydro-Québec criteria and directives

The *transmission provider* studies and takes into account the following factors during the *interconnection study*:

- equipment ampacity
- impact on *transmission system* reliability and service quality
- *transmission system* transient and dynamic stability, as well as voltage stability
- *transmission system* short-circuit levels
- impact of electrical losses on the *transmission system*
- impact on the *transmission system* protection
- impact on equipment connected to the *transmission system*
- impact on *transmission system* operation and maintenance

Once the *transmission provider* has completed the *interconnection study*, it submits to the *power producer* the information stipulated in the *interconnection study* agreement between the two parties. Such information may include the following:

- the *point of interconnection* between the *power plant* and the *transmission system*
- the voltage of the connection to the *transmission system*
- *network upgrades* required to connect the *power plant*
- the schematic diagram of the connection between the *power plant* and the Hydro-Québec *transmission system*
- *transmission system* contribution to short-circuit levels at the *point of interconnection*
- operating restrictions
- preliminary data on typical lead times and costs for *network upgrades*
- a technical report on special and conventional protection system requirements in light of the *power plant* project in question
- additional connection requirements that may apply to the *power plant* project, including the impedance and time constant limits for *synchronous generators* stipulated in Section 6.6 and impedance limits for *power plant* step-up transformers stipulated in Section 6.9.3
- if need be, any additional requirement related to the *bulk power system*

Besides the information in the *interconnection study*, the *transmission provider* may submit the following information as needed to the *power producer*:

- relevant characteristics of the Hydro-Québec line and substation to which the *power plant* is to be connected

- allowable emission limits to power quality disturbances applicable to *facilities* connected to the Hydro-Québec *transmission system*, as described in Section 5.4.

3.2.3 *Facilities study*

If in light of the *interconnection study* results the *power producer* decides to proceed with its connection project, the *transmission provider* will then conduct a *facilities study* to have a more precise engineering assessment of the content, costs and lead times for the upgrades and modifications to the Hydro-Québec *transmission system* needed to connect the *power plant*. The magnitude of the study will depend on that of the project.

Once the *transmission provider* has completed the *facilities study* it will provide additional information that the *power producer* may need to build its *facilities* to meet *transmission provider* requirements, including:

- the estimated duration of the work on the Hydro-Québec *transmission system* required to connect the *power producer*'s *power plant*
- (if needed) additional data on the power system to enable the *power producer* to conduct the emission study for power quality to demonstrate that its *facilities* meet applicable requirements (see Section 5.4)
- data required to calculate rises in ground potential
- (if needed) the value of the neutral reactor of step-up transformers used to connect the *power plant*
- the location of the *switchyard*

3.2.4 Protection study for *power producer facilities*

So the *facilities study* can be accurate and effective, the *transmission provider* may first require that the *power producer* submit a preliminary study of the protection systems for its *facilities*, particularly when additions or changes to protection equipment amount to a large portion of *power plant* connection costs. The preliminary study must essentially cover the relevant information outlined in Appendix C herein.

In any event, the *power producer* must submit to the *transmission provider* a final study of the protection systems for its *facilities* before starting to implement its project. That study must cover all relevant information outlined in Appendix C herein.

The *power producer* must have the *transmission provider* approve all protection system settings it intends to use to meet the requirements of the Hydro-Québec *transmission system* given in Section 7.4. Furthermore, the *power producer* must submit to the *transmission provider*, before commissioning its *power plant*, a confirmation that those settings will be applied to the protection systems for its *facilities*.

4. General Requirements

4.1 *Bulk power system*

It is the *transmission provider*'s responsibility to design, operate and maintain the Hydro-Québec *transmission system* in accordance with *good utility practice* and Hydro-Québec criteria and directives. Furthermore, since Hydro-Québec is an *NPCC* member, the *transmission provider* must also design, operate and maintain the Hydro-Québec *bulk power system* following *NPCC* and *NERC* criteria and guidelines.

The *transmission provider* will determine during the *interconnection study* whether *power producer facilities* are part of the *bulk power system*. If they are, the *power producer facilities* are also subject to design, operation and maintenance requirements applicable to the *bulk power system* as described in *NPCC* documents. Such supplementary requirements cover:

- special protection, conventional protection and telecommunication systems, which must meet requirements in *NPCC* Document A-5 Bulk Power System Protection Criteria
- maintenance of the systems above, which must comply with directives in Document A-4 Maintenance Criteria for Bulk Power System Protection
- proof of compliance with the *bulk power system* criteria in Document A-2, Basic Criteria for Design and Operation of Interconnected Power Systems, prepared in compliance with Document B-4 Guidelines for NPCC AREA Transmission Reviews
- parts applicable to *power producers* of Document A-3 Emergency Operation Criteria, B-1 Guide for Application of Autoreclosing to the Bulk Power System, B-7 Automatic Underfrequency Load Shedding Program Relaying Guideline, C-16 Procedure for NPCC Review of New or Modified Bulk Power System Special Protection Systems (SPS), C-22 Procedure for Reporting and Reviewing Proposed Protection Systems for the Bulk Power System and C-29 Procedures for System Modeling: Data Requirements & Facility Rating

These documents are available on the *NPCC* Web site at:
www.npcc.org/documents/regStandards/Directories.aspx .

4.2 General requirements for the design, construction and operation of *power producer facilities*

Power producer equipment and *facilities* must comply with codes, standards and rules applicable in Québec, and with *good utility practice*.

Generating equipment connected to the *transmission system* must be three-phase.

4.2.1 Requirement regarding maximum loss of generation following a single-element contingency

All *power producer facilities* connected to a *power plant* with an installed capacity exceeding 1000 MW must be designed, built and operated so that a single-element contingency in those *facilities* cannot result in a loss of generation exceeding 1000 MW. Single-element contingency means the failure, malfunction or accidental operation of any system, device or component that is part of the *power producer facilities*. This requirement also applies to *power plants* connected through a *neighboring system within Québec*.

4.2.2 Requirements for *power plant* response to *disturbances* on the *transmission system*

Section 14.2 describes the requirements for wind *power plants* during such *disturbances*.

It is essential that generating *facilities* connected to the Hydro-Québec *transmission system* remain in service without *tripping* as long as possible when *disturbances* occur on the *transmission system* so that they can both help maintain grid stability and restore the voltage and frequency, and not interfere with special and conventional protection systems acting on the grid.

4.2.2.1 Minimum requirements for all *power plants*

Power producer facilities must be designed, built and operated to remain in service, without directly or indirectly causing a *generating unit* to trip, when voltage and frequency deviations occur following a *disturbance* for the durations given in Table 1 and 2.

A number of faults on the *transmission system* cause voltage to drop to levels below 0.75 p.u. (see Table 1). *Power producer facilities* must remain in service without a *generating unit tripping* during a fault on the *transmission system* (including one on the high-voltage side of the *switchyard*) and for the time required to restore voltage after the fault is cleared, whether it is:

- a three-phase fault cleared in 0.15 seconds
- a two-phase-to-ground fault or phase-to-phase fault cleared in 0.15 seconds, or
- a single-phase-to-ground fault cleared in 0.30 seconds

Furthermore, *power producer facilities* must remain in service without a *generating unit tripping* during a remote fault cleared by a slow protective device (up to

45 cycles) and for the time required to restore voltage after the fault is cleared, whether it is:

- a three-phase fault, provided the positive-sequence voltage on the high-voltage side of the *switchyard* does not fall below 0.25 p.u.
- a two-phase-to-ground fault, provided the positive-sequence voltage on the high-voltage side of the *switchyard* does not fall below 0.5 p.u.
- a phase-to-phase fault, provided the positive-sequence voltage on the high-voltage side of the *switchyard* does not fall below 0.6 p.u.
- a phase-to-ground fault, provided the positive-sequence voltage on the high-voltage side of the *switchyard* does not fall below 0.7 p.u.

Power producer facilities must also help restore the power system to normal operating conditions after a *disturbance*.

Fault-clearing times longer than those above may be agreed upon with the *power producer* if such a solution is more advantageous overall.

Table 1 – Voltage ranges vs. minimum time before *generating unit tripping* following a *disturbance*

Undervoltage (p.u.) [1]	Overvoltage (p.u.) [1]	Minimum time
1.0 > V ≥ 0.90	1.0 ≤ V ≤ 1.10	Extended [2]
	1.10 < V ≤ 1.15	300 seconds
0.90 > V ≥ 0.85	1.15 < V ≤ 1.20	30 seconds
0.85 > V ≥ 0.75	1.20 < V ≤ 1.25	2 seconds
0.75 > V ≥ 0.25		1 second
0 ≤ V < 0.25		0.15 second
	1.25 < V ≤ 1.40 [3]	0.10 second
	V > 1.40 [3]	0.033 second

1 – Positive-sequence voltage on high-voltage side of *switchyard*

2 – Up to several hours, depending on time needed to bring grid back to normal state, i.e., within steady-state voltage range (see Section 5.1)

3 – Though temporary blocking is allowed for *facilities* using power electronics when the voltage exceeds 1.25 p.u., normal operation must resume once the voltage drops back below 1.25 p.u.

Table 2 – Frequency ranges vs. minimum time before *generating unit tripping* following a *disturbance*

Underfrequency (Hz)	Overfrequency (Hz)	Minimum time
59.4 ≤ F ≤ 60.0	60.0 ≤ F ≤ 60.6	Unlimited
58.5 ≤ F < 59.4	60.6 < F ≤ 61.5	11 minutes
57.5 ≤ F < 58.5	61.5 < F ≤ 63.0 [1]	1.5 minutes
57.0 ≤ F < 57.5		10 seconds
	63.0 < F ≤ 66.0 [1, 2]	5 seconds
56.5 ≤ F < 57.0		2 seconds
55.5 ≤ F < 56.5		0.35 second
F < 55.5	F > 66.0 [1, 2]	Instantaneous

1 – Instantaneous *tripping* at a frequency F ≥ 61.7 Hz is allowed only for *power plants* with *synchronous generators* whose total capacity does not exceed 300 kW, for *power plants* with *asynchronous generators*, and for thermal, wind and photovoltaic *power plants*.

2 – Instantaneous *tripping* at a frequency ≥ 63.5 Hz is allowed for *power plants* connected to the distribution system.

Power plants must also be able to remain in service when *disturbances* occur and the system frequency varies by ±4 Hz/s.

That requirement and the one governing frequency ranges and minimum times that *power plants* must remain in service without *generating unit tripping* (see Table 2) also apply to *power plants* connected through the distribution system, a *neighboring system within Québec*, a *municipal system* or the *SJBR electricity cooperative*.

Various protection systems, especially voltage and frequency protections, are used by the *power producer* to protect its generating equipment against potential damage from voltage and frequency deviations. No *power producer facility* protection can, however, directly or indirectly result in *generating unit tripping* for the voltage and frequency deviations specified in Tables 1 and 2.

4.2.2.2 Additional requirements for *power plants* protecting the integrity of *transmission system* equipment

Beyond the minimum requirements in Section 4.2.2.1, some *power plants* the operation of which is needed to protect the integrity of *transmission system* equipment (discussed below) must remain in service without *generating unit tripping* despite overvoltages that may arise from system separation or instability on part or all of the *transmission system*. *Power producer facilities* subject to such additional requirements must be designed, built and operated to remain in service without directly or indirectly causing *generating unit tripping* when voltage deviations occur for the durations in Table 3.

The SPSR (protection System to limit overvoltages during a separation of the TransÉnergie 735-kV transmission system) and other special protection systems are designed to protect the integrity of *transmission system* equipment during exceptional *disturbances* that may lead to instability on part or all of the *transmission system*. In order to limit the magnitude of potential overvoltages when such *disturbances* occur, it is crucial that some generating equipment connected to the *transmission system* remain in service without *tripping* until the special protection systems respond. The *power plants* called upon to perform this function are generally large ones (several hundred MW) connected to points along the 735-kV transmission system or to substations electrically close to it, especially in the northern part of the grid. It is up to the *transmission provider* to determine during the *interconnection study* whether the new *power plant* to be connected must help perform this function.

Table 3 – Overvoltage ranges vs. minimum time following a *disturbance* before *generating unit tripping* at *power plants* ensuring system equipment integrity

Overvoltage (p.u.) [2]	Minimum time
$1.0 \leq V \leq 1.10$	Extended [3]
$1.10 < V \leq 1.15$	300 seconds
$1.15 < V \leq 1.20$	30 seconds
$1.20 < V \leq 1.25$	5 seconds
$1.25 < V \leq 1.40$	2.5 seconds
$1.40 < V \leq 1.50$	0.10 second
$V > 1.50$	0.033 second

1 – These *power plants* must also comply with minimum times and undervoltage ranges given in Table 1.

2 – Positive-sequence voltage on high-voltage side of *switchyard*

3 – Up to several hours, depending on time needed to bring grid back to normal state, i.e., within steady-state voltage range (see Section 5.1)

4.2.3 *Power plant* islanding

Unless studies have first been conducted and a special agreement reached, *power producer facilities* must not supply in *islanded* mode the loads of customers connected to the Hydro-Québec *transmission system* or of Hydro-Québec customers connected to a *neighboring system within Québec*. The *power producer* may, however, island on its own loads and then assume the risks associated with self-supply.

4.2.4 Blackstart capability

Under *NERC* requirements, the *transmission provider* must devise a strategy for re-energizing the *transmission system* after a blackout. To do this, the *transmission provider* must rely on a number of generating *facilities* with blackstart capability to keep voltage and frequency at adequate levels for *transmission system facilities* and for other generating *facilities* to return to service. Following the *interconnection study*, the *transmission provider* may require that the *power producer* equip its *power plant* with a number of *synchronous generators* having blackstart capability.

4.3 Access to *power producer facilities* and property rights for the tie line

Under the interconnection agreement, the *transmission provider* or its agent must have access at reasonable hours to the *power producer*'s property and *facilities* to perform such tasks as installing, building, operating, maintaining, repairing, modifying or removing equipment that belongs to it. The *transmission provider* must also have access to telecommunication links used for protection and telemetry.

If it is a matter of personal safety or *transmission system* security, or when *transmission system* or telecommunication link failures occur, the *transmission provider* or its agent must be able to access *power producer facilities* at all times with no further ado.

The *power producer* must assign to the *transmission provider* real rights on its property so the latter can erect the tie line(s) needed between its *power plant* and the *transmission system*. It must also conform to the electrical clearances for the line(s) in accordance with *transmission provider* standards.

5. Voltage- and Frequency-Related Requirements

5.1 Steady-state voltage ranges

The steady-state voltage may deviate from the nominal voltage by ±6% on 44-kV and 49-kV Hydro-Québec *transmission systems* and by ±10% on 69-kV or higher systems, except for the 735-kV system where the range is from -5% to +4%. On some portions of the system, the allowable steady-state voltage range may differ from the values above to account for the characteristics of existing infrastructure or specific operating constraints.

Power producer facilities must be designed to generate and deliver to the *point of interconnection* the projected maximum real power in the prescribed voltage range of the system to which the facilities are connected. Note that voltage variations on the medium-voltage side of *power producer facilities* may differ from those of the transmission system, due in particular to reactive power supplied or absorbed by generating equipment.

Greater variations in voltage may occur following *disturbances*.

5.2 Steady-state frequency range

The steady-state frequency of the Hydro-Québec *transmission system* may deviate from its nominal 60 Hz by ±1%, i.e., from 59.4 to 60.6 Hz.

Power producer facilities must be designed to generate and deliver to the *point of interconnection* the projected maximum real power in the prescribed frequency range of the *transmission system*.

Greater variations in frequency may occur following *disturbances*.

5.3 Voltage regulation, excitation system and frequency control

Voltage regulation and frequency control are essential for maintaining *transmission system* stability and reliability. High-performance excitation systems and speed governors are crucial in achieving this. To be effective, a large majority of *power plants* must help assume these functions.

The *transmission provider* may require that *power producer facilities* help maintain system voltage and frequency as described in Sections 5.3.1 to 5.3.3 below.

5.3.1 Voltage regulation

Note: Section 14.3 covers voltage regulation requirements for wind generators.

Power plants connected to the *transmission system* must help achieve steady-state, dynamic and transient voltage regulation.

To do so, every conventional *synchronous generator* synchronized to the grid must be equipped with an automatic voltage regulation system and be able to supply or absorb, under steady-state conditions, the reactive power needed to maintain the voltage, and do so up to the power factor values given in Section 6.7.

For any other kind of generating equipment, voltage regulation may be achieved by the *generating units* or by other equipment that the *power producer* adds to its *power plant* (e.g., static or synchronous compensators). Voltage regulation performance of the *power plant* must, however, always be comparable to that of one with conventional *synchronous generators*.

The *transmission provider* may waive the requirement for an automatic voltage regulation system in the case of a *power plant* with an installed capacity of less than 10 MW, especially when the short-circuit level at the *point of interconnection* is much greater than the installed capacity of the *power plant*.

Available reactive power at the *point of interconnection* must not be limited by any component of the *power producer facilities* (e.g., cables or excitation limiters).

In order that the *transmission provider* may later be able to implement a regional voltage control system, 100-MW or higher *power plants* connected to the *transmission system* must be designed and built to support system voltage regulation commands from an external source.

5.3.2 Static excitation system

Every 20 MW or higher synchronous generating unit in a *power plant* whose present or ultimate installed capacity is 100 MW or more must be equipped with a static excitation system and a stabilizer. The characteristics of excitation systems for *synchronous generators* must meet the requirements in the CEGR reference document for general electrical characteristics entitled “Système d’Excitation Statique pour les Alternateurs” [static excitation systems for generators] or any later version thereof. The stabilizer must be a delta-omega multiband power system stabilizer (MB-PSS) certified by Hydro-Québec as stipulated in the CEGR reference document “Stabilisateur Multi-Bandes de Type Delta-Oméga” or any later version thereof. The *transmission provider* specifies the settings to be used during project implementation but may revise them as the *transmission system* evolves. The reference documents above are available at:

http://www.hydroquebec.com/transenergie/en/commerce/producteurs_prives.html .

For a new *power plant* built in a *major load centre* or *modification* of the static excitation system of a *power plant* in a *major load centre*, the *transmission provider* may allow the static excitation system to have a lower ceiling value than that in the first of the two references above, provided the benefits or performance for local and main power systems is undiminished compared to static excitation with a stabilizer as specified in the first paragraph of this subsection.

Similarly, for the *modification* of a slow static excitation system in a *power plant* in a *major load centre*, the *transmission provider* may allow an excitation system whose performance at least matches that of a system with a rotating diode exciter, provided the benefits or performance for local and main power systems is undiminished compared to static excitation with a stabilizer as specified in the first paragraph of this subsection.

For 20 MW or lower synchronous *generating units* or for a *power plant* whose present or ultimate installed capacity is less than 100 MW, the *transmission provider* may require, based on *interconnection study* results, that synchronous *generating units* have static excitation systems with stabilizers. This may arise especially if the *power plant* is far from the Hydro-Québec main power system or if the *power plant* must occasionally be synchronized to a neighboring system over a portion of the Hydro-Québec *transmission system*.

5.3.3 Frequency control

Section 14.4 covers frequency control requirements for wind generators.

In order to contribute to system frequency control, all *generating units* with a rated capacity of over 10 MW that are synchronized to the *transmission system* must have a speed governor system with a permanent speed-droop (sigma) having a range adjustable over at least 0% to 5% and no frequency deadband. Asynchronous *generating units* able to control frequency and having a rated capacity above 10 MW must, to contribute to system frequency control, be equipped with a feedback system performing similar functions. This requirement also applies to *generating units* connected through distribution system facilities, a *neighboring system within Québec*, a *municipal system* or the *SJBR electricity cooperative*.

Based on *interconnection study* results, however, the *transmission provider* may require a speed governor on *generating units* with a rated capacity below 10 MW, especially if it is anticipated that in particular situations the *power plant* may be islanded onto loads normally connected to the Hydro-Québec *transmission system*. Furthermore, if the *power plant* may have to be restarted in islanded mode, it must have blackstart capability.

Despite the above, the *transmission provider* may for some system configurations require that the speed governor be temporarily disabled after synchronizing to the Hydro-Québec *transmission system* to minimize the risk of unwanted *islanding* of the *power plant* onto a customer load connected to the *transmission system*.

5.4 Power quality – emission limits

The requirements below are designed to limit power quality *disturbances* originating from *power producer facilities* to avoid compromising the quality of the electricity supply to customers connected to the Hydro-Québec *transmission system*.

Power producer facilities must be designed and operated to meet requirements set down in the latest version of Emission Limits for Customer Facilities Connected to the Hydro-Québec Transmission System, which is available at:

http://www.hydroquebec.com/transenergie/en/commerce/producteurs_prives.html .

Limits apply to the following *disturbances*: harmonics and telephone influence, voltage and load imbalances, rapid voltage changes and flicker. During the *interconnection study*, the *transmission provider* determines whether emission studies are required, and if so specifies the assessment methods to be used based on *power producer* technology and on stipulations in Section 5.4.1 to 5.4.3 below.

To ensure that *power producer facilities* meet allowable emission limits under all foreseeable operating conditions, the *transmission provider* may further require of the *power producer* that tests or measurements be performed before final approval for the *facilities* is given. Other tests and measurements may later be required to ensure ongoing compliance with emission limits.

5.4.1 Rapid voltage changes and flicker

Rapid voltage changes and flicker are randomly or regularly repeating *disturbances* that may impair the proper functioning of sensitive equipment. Such *disturbances* may be caused by switching operations (say of capacitor banks) producing rapid variations in reactive power, by switching power equipment on and off, by repeatedly energizing power transformers, by the continuously varying output of wind generators, etc.

A *power producer* whose *facilities* can cause such voltage variations must submit to the *transmission provider* an emission study conducted by a professional engineer in order to demonstrate that its *facilities* are designed to meet allowable limits. As input to that study, the *transmission provider* will give the *power producer* the power system characteristics to be used for emission level calculations under foreseeable operating conditions. Transient non-repetitive *disturbances* lasting less than two 60-Hz cycles are generally ignored in the calculations but may in some cases be covered by specific limits.

5.4.2 Harmonics

Harmonics produced by some types of *facilities* may cause voltage and current distortion producing interference in communication networks. *Power producer synchronous generators* must thus comply with the test requirements for harmonics and telephone interference stipulated in International Electrotechnical Commission standards (IEC 60034 series) or their equivalent. These standards can be ordered from the Standards Council of Canada site at: www.scc.ca/en/index.shtml.

Asynchronous generators must perform similarly. The performance is to be confirmed by testing and documented in the test reports stipulated in Section 12 herein.

If *power plant* equipment (other than *synchronous* and *asynchronous generators* meeting the standards above), e.g., power converters, can produce harmonics, the *power producer* must, at the *facilities* design stage, conduct a study of harmonic emissions propagating from its *facilities* to the *transmission system*. In order to demonstrate that *power producer facilities* are designed to meet allowable limits, the study above must be conducted by a professional engineer using the methods specified in Emission Limits for Customer Facilities Connected to the Hydro-Québec Transmission System or any revised version thereof and be submitted to the *transmission provider* for acceptance.

To conduct the emission study, the *power producer* needs information on harmonic impedance loci of the Hydro-Québec *transmission system*. The *transmission provider* communicates that information at the *facilities study* stage.

5.4.3 Additional power quality requirements

Given the diverse features of electricity generating equipment and progress in the underlying technology, the *transmission provider* may specify, as needed, additional power quality requirements that *power producer facilities* must meet to preserve adequate service quality. Without restricting this general principle, such additional requirements may be specified based on the type of generation, on how *power producer facilities* are connected and on the characteristics of the portion of the grid to which they are connected. This may be the case, for instance, if *facilities* are connected at a point where the ratio of *transmission system* short-circuit level to *power producer facility* capacity is low. After assessing the situation, the *transmission provider* may add, when appropriate, any such requirements at the *facilities study* stage or as soon as the characteristics of *power producer facilities* affecting power quality are known.

5.5 Synchronization

To limit *disturbances* in the *transmission system* during synchronizing operations on its *generating units*, the *power producer* must equip its *facilities* with a frequency synchronization system for *synchronous generators* or a speed-monitoring system for *asynchronous generators*.

The *transmission provider* may require that operations to synchronize *power producer generating units* to the *transmission system* be performed on the high-voltage side of the step-up transformers. The *interconnection study* determines where this is to be done.

6. Equipment-Related Requirements

Following standards and industry practices, the *power producer* must conduct engineering studies, particularly short-circuit and insulation coordination studies, in order to adequately determine the characteristics of equipment in its *power plant* to be connected to the *transmission system*. The requirements below are minimum requirements strictly from a *transmission system* standpoint.

6.1 Grounding connection

The grounding connection is the way the neutral point of an equipment unit or *facility* is electrically connected to ground.

6.1.1 *Transmission system* grounding connection

Most of the *facilities* on the Hydro-Québec *transmission system* are effectively grounded, i.e., meet the following conditions:

$$0 \leq X_0/X_1 \leq 3 \quad \text{and} \quad 0 \leq R_0/X_1 \leq 1$$

where:
X_1 = positive-sequence reactance of the system
X_0 = zero-sequence reactance of the system
R_0 = zero-sequence resistance of the system

There are parts of the 69-kV or lower *transmission system*, however, where the neutral is not effectively grounded. The zero-sequence impedance is then higher than for the criteria above.

The characteristics of the *transmission system* grounding connection can affect ground fault levels, the interrupting capacity of circuit breakers, overvoltages and equipment insulation levels, surge arrester characteristics, the type of connection of transformer windings, protection system characteristics and settings, etc. *Power producer facilities* must thus be of adequate design and compatible with the characteristics of the Hydro-Québec *transmission system* grounding connection under both normal and fault conditions.

The requirements in Section 6.1.2 and 6.1.3 are intended to limit any temporary overvoltage arising when Hydro-Québec *transmission system* breakers open first to isolate a ground fault on the portion of the system to which *power producer facilities* are connected.

6.1.2 Effectively grounded system

If the neutral point on the Hydro-Québec *transmission system* is effectively grounded under normal conditions, the *switchyard* must have an effectively grounded neutral point connection seen from the high-voltage side.

To meet this condition, the neutral on the high-voltage windings of the step-up transformer(s) used to connect the *power plant* must be grounded. Furthermore, impedance values for the transformer(s) and winding connections must be such that the *power producer facilities* meet the criteria for effective grounding:

$$0 \leq X_0/X_1 \leq 3 \quad \text{and} \quad 0 \leq R_0/X_1 \leq 1$$

where:

X_1 = positive-sequence reactance of the *power plant* seen from the high-voltage side of the *switchyard*
X_0 = zero-sequence reactance of the *power plant* seen from the high-voltage side of the *switchyard*
R_0 = zero-sequence resistance of the *power plant* seen from the high-voltage side of the *switchyard*

If generation is interconnected to the *transmission system* through existing *facilities* (e.g., *industrial customer facilities* or *satellite substations*), the above requirements for the grounding connection also apply, X_1, X_0 and R_0 then being calculated for the high-voltage side of the *industrial customer*'s substation or the *satellite substation*. The following means may then be used to meet those requirements:

- adding grounding transformer(s) on the high-voltage side of the *industrial customer*'s substation or *satellite substation*
- modifying the connection type of existing transformer windings in the substation in question
- taking into account the effect on the grounding connection of other transformers connected to the same transmission line
- adding a *remote tripping* system to the *power plant* if grid characteristics so permit without overly degrading service to other *customers*

Depending on the characteristics of the *transmission system* near the *point of interconnection*, it may be necessary to limit the ground fault current contribution of the *power plant* substation. Additional requirements may be specified to achieve this, such as adding a reactor seen from the high-voltage side of each transformer between the neutral and ground or using YN-connected transformers with an appropriate zero-sequence impedance on the high-voltage side (the winding on the low-voltage side is generally floating). If such a limit to the ground fault current contribution of the *power plant* is required on a portion of the grid, the *transmission provider* will determine zero-sequence impedance or neutral reactor values at the *facilities study* stage based on the criteria above.

6.1.3 Non-effectively grounded system

The *transmission provider* requires that *facilities* connecting a *power plant* to a portion of the Hydro-Québec *transmission system* where the neutral is not effectively grounded under normal conditions be designed taking that fact into account in order to avoid contributing more than 400 A to the single-phase fault current on that portion of the grid. If power system characteristics permit, the *transmission provider* and *power producer* may agree to a higher fault current contribution.

A grounding transformer of appropriate impedance will also generally be required on the high-voltage side of the *switchyard* or *satellite substation* to keep the zero-sequence impedance from becoming capacitive due, for instance, to the capacitive effect of lines or cables on the *transmission system* side.

6.2 General electrical characteristics of equipment

The electrical characteristics of equipment forming the *power producer facilities* must be compatible with those of the *transmission system* to which the *facilities* are connected, especially regarding insulation coordination. Table 4 gives present standard values for insulation and short-circuit levels on the *transmission system*. In designing its *facilities*, it is recommended that the *power producer* check with the *transmission provider* to confirm the electrical characteristics that apply to the portion of the *transmission system* to which its *facilities* are to be connected.

A *power producer* installing equipment with an interrupting capacity or short-circuit rating below the standard short-circuit levels set by the *transmission provider* will have to pay to replace such equipment if the capacity or rating becomes too low as the *transmission system* evolves.

Table 4 – Standard insulation and short-circuit levels for Hydro-Québec *transmission system* equipment

Nominal voltage of system [1] (kV L-L rms)	Rated voltage of equipment (kV L-L rms)	Ground insulation level [2]		Standard short-circuit levels [3] (kA sym. rms)
		Lightning (kV p-p)	60 Hz (kV rms)	
69	72.5	350	140	31.5
120	145	550	230	40
161	170	650–750 [4]	275–325 [4]	31.5 and 50 [5]
230	245	850–950 [4]	360–395 [4]	31.5 and 50 [5]
315	330	1050–1175 [4–6]	460	31.5 and 50 [5]

1. Levels have not been standardized for 44- and 49.2-kV systems and must be confirmed on a case-by-case basis. Values for the 735-kV system must also be confirmed on a case-by-case basis.
2. Other requirements also apply to disconnect switches, whose insulation level between open contacts must be higher than the ground insulation level.
3. The X/R ratio used for these voltage levels is 30.
4. The lower value applies to transformers and shunt reactors protected by surge arresters at their terminals; the higher value applies broadly to all other equipment.
5. The short-circuit level depends on the specific characteristics of the system under consideration.
6. The switching impulse withstand voltage is 850 kV peak.

6.3 *Connection switches (disconnecting switches)*

For the safety of employees working on the power system, the *transmission provider* requires that *power producer facilities* can be disconnected from the *transmission system* at a visible disconnection point accessible to it. The disconnection point must be located as close as possible to the *point of interconnection*.

A disconnecting switch, also called the *connection switch*, installed at each *point of interconnection*, generally acts as the disconnection point. It must be possible to lock out the *connection switch* in the open position (blades opening upwards forming an angle greater than 90°). For motorized disconnecting switches, it must be possible to disable and lock out the drive control mechanism.

In some cases, the *transmission provider* may allow some device other than a disconnecting switch (e.g., a rack-mounted circuit breaker) to act as a disconnection point.

In all cases, the *power producer* must submit the equipment's specifications to the *transmission provider*, which checks that they comply with its safety requirements.

In no instance may a *connection switch* be coupled, on the *transmission system* side, to a grounding switch that grounds automatically when the *connection switch* opens.

6.4 Surge arresters on the high-voltage side of the *switchyard*

If the *power producer*'s *switchyard* has high-voltage surge arresters, they must be located on the *power plant* side of the *connection switch*, unless the *transmission provider* agrees otherwise, so they can be isolated from the *transmission system* without de-energizing the *transmission provider*'s line.

Surge arresters must be of the zinc oxide type with no spark gap and appropriately rated for constraints (in particular for temporary overvoltages) on the *transmission system* and on the *facilities* to which they are connected.

6.5 Breakers

Breakers must have adequate insulation withstand and interrupting capacity (transient recovery voltage [TRV], recovery voltage [RV], short-term withstand current, short-circuit interrupting capacity, etc.) to interrupt any kind of fault on the *power producer facilities* or on any part of the Hydro-Québec *transmission system* to which those *facilities* are connected. Particular care must be taken regarding insulation and out-of-phase faults to ensure that the breakers have the required interrupting capacity.

6.5.1 *Tie breakers*

As stipulated in Section 3.1.2, the *power producer* must equip its *facilities* with one or more *tie breakers*. The devices must be able to perform an open-close-open (O-C-O) cycle for eight hours with no power from the grid.

If a *tie breaker* has a built-in system for detecting faulty internal states (e.g., SF_6 density too low) that can force it to close or disable its normal functioning (e.g., locking its state), the *power producer* must, when a faulty state is detected, remove the breaker in question from operation as quickly as possible to avoid damage to its *facilities* or undue *disturbances* on the *transmission system*. The *power producer* must submit to the *transmission provider* for approval the measures it intends to take to meet this requirement.

6.6 *Synchronous* and *asynchronous generators*

Power producer facilities, particularly *synchronous* and *asynchronous generators*, must be designed to support without *tripping* voltage imbalances of up to 2% (negative-sequence component, V_2/V_1) under steady-state conditions on the Hydro-

Québec *transmission system* and even greater imbalances for a limited time (e.g., a 50% voltage imbalance under fault conditions).

Following the *interconnection study*, the *transmission provider* may impose additional requirements on certain impedance or time constant values for *synchronous generators* (e.g., maximum X"q/X"d, maximum X'd or maximum T'do) to ensure *transmission system* stability is maintained. To give an idea, X"q/X"d for *synchronous generators* now connected to the Hydro-Québec grid generally ranges from 1.0 to 1.3, and the typical X'd is 0.3 p.u. based on equipment MVA. The typical time constant T'do is 6.0 seconds.

Section 5.4.2 covers harmonics (waveform and interference).

6.7 Design power factor of generating equipment

Section 14.3 describes power factor requirements for wind generators.

The power factors specified below set upper and lower thresholds to the range of reactive power that *power producer facilities* must make available to the grid under steady-state conditions.[3]

6.7.1 Conventional *synchronous generators* synchronized to the grid

Conventional *synchronous generators* must have a rated power factor not exceeding:

- 0.90 in over-excited mode
- 0.95 in under-excited mode

The power factors are specified at the *synchronous generator* terminals.

For *power plants* with the *point of interconnection* on the high-voltage side of the *switchyard*, the power factor in over-excited mode must also not exceed 0.95 at the *point of interconnection*.

However, if the *interconnection study* shows that reactive power from *synchronous generators* cannot be completely used by the *transmission system*, the *transmission provider* may allow a power factor at the generator terminals in over-excited mode exceeding 0.90 but not 0.95. For *power plants* with the *point of interconnection* on the

[3] If the *power plant* is connected through *industrial customer facilities*, that customer must comply with the power factor stipulated in the *distributor*'s conditions governing the supply of electricity. A metering system able to distinguish between the industrial consumer and generation parts must be installed so the real contribution of the *power plant* can be deducted from load consumption and thus verify that power factor requirements are being met.

high-voltage side of the *switchyard*, the power factor in over-excited mode must not exceed 0.97 at the *point of interconnection*.

Generators in *power plant* that have an installed capacity of less than 10 MW and that are not required to help in voltage regulation, as stipulated in Section 5.3.1, must supply sufficient reactive power to keep the power factor at 1.0 on the high-voltage side of the *switchyard*.

6.7.2 Other types of generating equipment

For any other type of generating equipment, the *power plant* must make available on the high-voltage side of the *switchyard* the range of reactive power corresponding to a rated power factor, in over- and under-excited mode, not exceeding 0.95. Available reactive power must at least correspond to a power factor of 0.95 of the rated power of the *generating units* in service.

However, if the *interconnection study* shows that reactive power from the *power plant* cannot be completely used on the *transmission system*, the *transmission provider* may accept a power factor on the high-voltage side of the *switchyard*, in over- and under-excited mode, greater than 0.95 though not exceeding 0.97.

Power plants which have an installed capacity of less than 10 MW and which are not required to help in voltage regulation, as stipulated in Section 5.3.1, must supply sufficient reactive power to keep the power factor at 1.0 on the high-voltage side of the *switchyard*.

6.8 Inertia constant of *generating units*

To maintain *transmission system* stability and integrity during *disturbances*, and to minimize the risk of oscillations between *power plants*, the inertia constant of *generating units* in a *power plant* connected to the Hydro-Québec *transmission system* must be compatible with the inertia constants of existing *power plants* in same region. The *interconnection study* will specify any minimum inertia constant that applies to *generating units* in the *power producer*'s *power plant*.

6.9 Step-up transformers

6.9.1 Taps

Unless otherwise stipulated at the time of the *interconnection study*, *power plant* step-up transformers must have taps to allow the transformer ratio to be adjusted based on voltage conditions on the *transmission system*. Taps must be chosen to avoid hampering present and future operation of the Hydro-Québec *transmission system* and to meet Section 5.1 requirements.

6.9.2 Winding connections of step-up transformers

Winding connections of *power plant* step-up transformers must meet the requirements in Section 6.1.2 or 6.1.3, as applicable.

6.9.3 Impedance values

Following the *interconnection study*, the *transmission provider* may specify (maximum or minimum) impedance limits for *power plant* step-up transformers, while meeting the requirements in Section 6.1.2 or 6.1.3, as applicable.

6.10 Possible system voltage changes on portions of the grid

To modernize its facilities or better meet customer needs, the *transmission provider* may change the nominal voltage of certain portions of its *transmission system* from that used at the time the *power plant* is connected.

The *interconnection study* will mention any such planned voltage change. *Power producer facilities* must then be designed to adapt to the multiple voltage levels specified in the study.

6.11 Tie lines built by the *power producer*

To maintain *transmission system* reliability and security, a *power producer* building a tie line to connect its *power plant* to the *transmission system* must make sure that the electrical and mechanical characteristics of the line are equivalent to those of one the *transmission provider* would build for a comparable project. In that case, the *transmission provider* will supply the *power producer* with specific design requirements based on the type of line and where it is to be built.

7. Protection System Requirements

7.1 General requirements

It is the *power producer*'s responsibility to adequately protect its *facilities* from *disturbances* arising in its *facilities* or on the Hydro-Québec *transmission system*.

The *power producer* must also procure and install in its *facilities* protection systems that can effectively protect the Hydro-Québec *transmission system*.

Coordination is required between the various protections installed by the *power producer* and those on the *transmission system*.

Other specific requirements based on the *interconnection study* or *facilities study* may be added to the ones in this Section.

7.1.1 Selectivity of protection systems on *power producer facilities* to *disturbances* on the *transmission system*

No *power producer facility* protection must, directly or indirectly, result in *generating unit tripping* within the steady-state voltage and frequency ranges specified in Section 5.1 and 5.2. Furthermore, as stipulated in Section 4.2.2.1, generating *facilities* connected to the Hydro-Québec *transmission system* must remain in service without *generating unit tripping* when *disturbances* occur on the *transmission system* to help maintain grid stability and restore voltage and frequency.

Systems protecting *power producer facilities* must thus be selective enough to avoid inadvertent *generating unit tripping* when disturbances occur. More specifically, no protection must result, directly or indirectly, in *generating unit tripping* for the voltage and frequency deviations given in Table 1 and 2 of Section 4.2.2.1. *Facilities* that are not likely to be damaged by greater voltage and frequency variations must remain in service beyond the minimum values in those tables.

Furthermore, as stipulated in Section 4.2.2.2, some *power plants* required to ensure the integrity of *transmission system* equipment must remain in service without *generating unit tripping* despite high overvoltages that may stem from system separation or instability on part or all of the *transmission system*. Protections for *power plant facilities* must also be selective (understood here as insensitive) to the voltage levels given in Table 3 of Section 4.2.2.2.

7.1.2 Requirements for *power plants* connected to the *bulk power system*

As stipulated in Section 4.1, additional requirements apply to *power producer facilities*, particularly telecommunication and protection systems, if the *interconnection study* shows that the *facilities* are part of the *bulk power system*. More specifically, the protection systems must meet the requirements in *NPCC* Document A-5, Bulk Power System Protection Criteria, or any later version thereof. Furthermore, maintenance of such protection systems must be carried out in accordance with the rules in *NPCC* Document A-4, Maintenance Criteria for Bulk Power System Protection, or any later version thereof.

7.1.3 Automatic *reclosing*

Unless a special agreement has been reached with the *transmission provider* following the *interconnection study*, automatic *reclosing* of *power producer facilities* is prohibited, regardless of whether the fault originates in those facilities or on the Hydro-Québec *transmission system*.

7.2 Grounding connection requirements

Section 6.1 requirements regarding the grounding connection are also intended to ensure that protection systems succeed in quickly detecting and clearing the *power plant* contribution to a fault in an area of the *transmission system* specified by the *transmission provider*.

If the *power plant* is connected to the *transmission system* through *industrial customer* or *satellite substation* transformers, the *transmission provider* may require, besides effective neutral grounding, additional protection systems, including *remote tripping* or teleprotection.

If the *power plant* is connected to a portion of the grid with non-effective neutral grounding under normal conditions, the *transmission provider* will systematically require protection systems suited to that situation.

7.3 Breaker requirements

All 230-kV or higher breakers must have two sets of trip coils with separate cores, each designed for both automatic trip circuits per protection. For lower voltage levels, the *transmission provider* may also require two sets of trip coils with separate cores if the need for grid protection so warrants.

7.4 Minimum protection function requirements for Hydro-Québec *transmission system* needs

The minimum protection functions that must be implemented to meet the needs of the Hydro-Québec *transmission system* are described below. The protection systems in question must, for the zone they are to circumscribe, detect any kind of fault or disturbance that may affect the Hydro-Québec *transmission system*, whether it originates in *power producer facilities* or on the Hydro-Québec *transmission system*. Protection systems triggered in such situations must isolate the faulted zone from the *transmission system*.

The *power producer* must submit its proposed protection systems to the *transmission provider* who will ensure that they meet the requirements herein.

7.4.1 Protection from faults in *power producer facilities*

The protection systems the *power producer* uses to detect faults in its *facilities* must be compatible and coordinated with those used on the *transmission system*. When triggered, *power producer* protection systems must quickly, reliably, selectively and safely isolate any kind of fault affecting the *facilities*. Note that the *transmission provider* may add specific requirements based on *interconnection study* results.

7.4.2 Protection from faults on the Hydro-Québec *transmission system*

The protection systems used to clear faults occurring on the Hydro-Québec *transmission system* vary depending on each *power plant*'s location, size, characteristics and means of generation (*synchronous generators*, *asynchronous generators*, etc.). They may also depend on the characteristics of the *transmission system* to which *power producer facilities* are connected. When triggered, such systems must quickly, reliably, selectively and safely remove the contribution of *power producer facilities* to any kind of fault.

Two primary protections (as defined below) each with a trip relay are needed. In some cases, a higher level of independence of the two primary protections may be required to meet the needs of the local *transmission system* to which *power producer facilities* are connected.

If the contribution of *generating units* to the *transmission system* fault is insufficient for the use of two primary protection systems, e.g., for *asynchronous generators*, the protection systems to implement will be dealt with in the technical report on project-specific special and conventional protection systems.

Primary protections are comprised of relays with the specific functions and settings below.

- Protection must cover all types of faults: three-phase, two-phase, two-phase-to-ground, and single-phase-to-ground with and without a fault impedance. For high-impedance faults, the fault resistance used must be Rf = 10 Ω, i.e., a zero-sequence component of 3Rf = 30 Ω.
- Tripping must not be intentionally delayed except as may be required for coordination with *transmission system* protection systems.
- Protection must be selective. The zone covered by the primary protection must be coordinated with protections in adjacent zones.

To the extent possible, such protections should not be of the same design or from the same manufacturer. They may require that telecommunication links be used.

7.4.3 Voltage protection, frequency protection and *remote tripping*

Protecting *power producer facilities* and the *transmission system* requires voltage protection and frequency protection, and may also require *remote tripping*.

7.4.3.1 Voltage protection

Section 14.5.1 covers voltage protection requirements for wind generators.

Voltage protection must include both an undervoltage function and an overvoltage function. Such protection must be selective enough to avoid inadvertent *tripping* when *disturbances* occur.

Voltage protection settings in *power plants* connected to the *transmission system* must comply with the steady-state voltage ranges in Section 5.1. To meet Section 4.2.2.1 requirements, voltage protection settings must further comply with the voltage ranges and minimum times in Table 1 of that Section. Table 1 shows, for instance, that an overvoltage relay with the trip threshold set to a voltage of 1.17 p.u. must not trip unless the positive-sequence voltage on the high-voltage side of the *switchyard* remains above 1.17 p.u. for 30 seconds.

Voltage protection settings in *power plants* ensuring system equipment integrity (the *interconnection study* identifying such plants) must further comply with the ranges and minimum times in Table 3 of Section 4.2.2.2.

Note that it is not necessary to have a relay for each of the values in Table 1 and 3.

7.4.3.2 Frequency protection

Section 14.5.2 covers frequency protection requirements for wind generators.

Frequency protection must include both an underfrequency function and an overfrequency function. Protection settings must in no instance interfere with the means implemented by the *transmission provider* to restore system frequency following a *disturbance*.

Frequency protection settings in *power plants* connected to the *transmission system* must comply with the steady-state frequency range given in Section 5.2. To meet Section 4.2.2.1 requirements, frequency protection settings must further comply with the frequency ranges and minimum times in Table 2 of that Section.

Note that it is not necessary to have a relay for each of the values in Table 2 (Section 4.2.2.1).

The requirements above also apply to *power plants* connected to the *transmission system* through the distribution system, a *neighboring system within Québec*, a *municipal system* or the *SJBR electricity cooperative*.

Power producers may use more sensitive underfrequency protection settings provided they demonstrate to the *transmission provider* that automatic load-shedding agreements have been signed with customers to offset loss of *power plant* generation should underfrequency protection trip the plant.

The underfrequency trip relay settings of all 20-MW or higher *generating units* must be checked at least as often as prescribed in *NPCC* Document A-4, Maintenance Criteria for Bulk Power System Protection. That document is available on the *NPCC* Web site and on the *transmission provider* Web site at:

http://www.hydroquebec.com/transenergie/en/commerce/producteurs_prives.html

7.4.3.3 *Remote tripping*

The *transmission provider* may require that the *power producer* install a *remote tripping* system:

- if the line *reclosing* time is short (less than 2 seconds)
- when unwanted *islanding* may occur
- as additional fault protection if existing *power producer facility* protections are not effective or selective enough to ensure adequate protection of the system for faults on the Hydro-Québec *transmission system*, or
- if self-excitation may occur, as when *islanding* a *power plant* with a capacitive load, such as a capacitor bank, filters, an unloaded line or a cable

Any failure of the *remote tripping* system must, after a time-lag set by the *transmission provider*, trip the *power producer*'s plant. If in the *transmission provider*'s opinion, *tripping* the *power plant* would lead to excessive *disturbances* on the *transmission system*, it may require that a second *remote tripping* system be installed.

7.4.4 Breaker failure protection

The *transmission provider* requires breaker failure or equivalent protection that trips the breakers in adjacent zones when a breaker used to meet *transmission system* protection needs refuses to trip.

For faults in *power producer facilities*, if rapid *tripping* is needed for Hydro-Québec *transmission system* needs, a remote protection system for breaker failures is implemented using a dedicated link to remotely trip breakers at Hydro-Québec source substations contributing to the fault.

7.4.5 Further considerations

Power producer facilities and the Hydro-Québec *transmission system* may interact to produce various phenomena affecting the *transmission system*, notably overvoltages. Overvoltages may, for instance, occur during switching operations or faults, or arise from self-excitation of *synchronous* or *asynchronous generators*, harmonic or subsynchronous resonance, ferroresonance or (current or voltage) imbalance.

It is the *power producer*'s responsibility to adequately design and protect its *facilities* from such overvoltages and other harmful phenomena. The *transmission provider* may require that the *power producer* install various systems in its *facilities* to adequately protect the *transmission system* and third-party *facilities* from such phenomena.

7.5 Minimum requirements for equipment associated with protections for Hydro-Québec *transmission system* needs

7.5.1 Protective and trip relays

Protective and trip relays used in the protection systems required to meet Hydro-Québec *transmission system* needs must be certified by the *transmission provider*. The *transmission provider* may, however, authorize for a specific project the use of relays with certification pending if it considers them acceptable.

Anti-*islanding* relays must only be used for that purpose.

7.5.2 Protection system settings

Control and protection schematics, the coordination study and settings for protection systems installed by the *power producer* must be submitted to the *transmission provider* for approval. The *power producer* must not modify settings for its protections without written authorization from the *transmission provider*. The *power producer* must carry out initial settings to the protective devices it installs and verify the devices regularly thereafter.

7.5.3 Protection system power supply

Protection systems required for the *transmission system* must remain functional should the station service supply fail. Such system must thus be powered by a storage battery, or a pair of storage batteries if the *transmission provider* so requires based on *interconnection study* results.

Each storage battery must have two chargers that can either run in parallel with the battery or back up each other. Battery backup time must be at least eight hours for each battery. If station services can be resupplied from another source, battery backup time can be reduced to two or four hours, depending on how long it takes to do so.

7.5.4 Voltage and current transformers

The *transmission provider* requires current and voltage transformers on each of the three phases of the supply to protection systems installed for Hydro-Québec *transmission system* needs. The transformers must have separate secondary windings in order to supply separately the two primary protection systems. They must comply with the most recent version in effect of the standards followed by the *transmission provider*, available at:

www.hydroquebec.com/transenergie/en/commerce/producteurs_prives.html.

The transformers must be located on the high-voltage side of the *switchyard* (see Figure 1 to 3 in Section 3.1.2.1 and 3.1.2.2).

7.6 Telecommunication systems for teleprotection functions

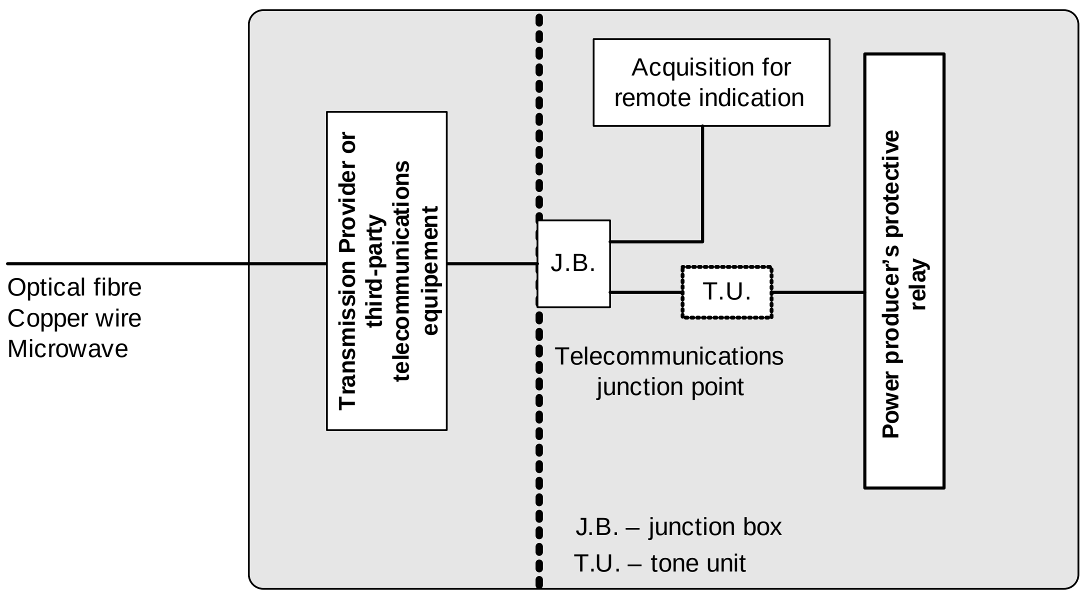
The *transmission provider* supplies, installs and maintains the equipment required for transmitting teleprotection signals.

Figure 4 shows the junction point between the Hydro-Québec or third-party telecommunication network and *power producer* equipment. The point is generally located at the junction box connecting telecommunication equipment (at the end of the link) to the tone unit (when present) or to the protective relay of the *power producer facilities*.

The kind of equipment to install, interface points and other characteristics relevant to providing the required services will be specified to the *power producer* at the *facilities study* or engineering study stage.

The *power producer* must provide adequate secure space for installing all equipment, and must install ductwork, junction boxes, and tone or teleprotection units that are part of the protection systems.

Figure 4 – Position of certain *power producer* devices relative to the telecommunications junction point



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8. Operation and Maintenance Requirements

8.1 Maintenance requirements for *power producer facilities*

To ensure grid reliability and Hydro-Québec employee safety, the *power producer* must maintain its equipment following existing standards and regulations, manufacturer requirements and industry practices, as stipulated in the interconnection agreement.

8.2 Operating requirements

Before *power producer facilities* are connected to the *transmission system*, the *power producer* and *transmission provider* must sign common operating instructions prepared by the latter. The instructions cover such matters as the ways the *power producer* and *transmission provider* communicate and operating conditions for *power producer facilities*. As stipulated in the interconnection agreement, the *power producer* must also have staff knowing Hydro-Québec's operating code and the terms and methods used by the *transmission provider* in applying safety measures.

Equipment used to connect *power producer facilities* to the *transmission system* must use the *transmission provider*'s nomenclature, which will be given to the *power producer* in the course of the project.

8.3 Data requirements for operating the *transmission system*

Section 14.6 covers specific information required for operating wind *power plants*.

To operate the Hydro-Québec *transmission system* efficiently, the *transmission provider* requires real-time data, in a form compatible with its equipment, from each *power plant* belonging to the *power producer facilities*. The minimal data required depends on *power plant* capacity and is given in Table 5 below.

The *power producer* must equip its *facilities* with all sensors needed to transmit the required data to the *transmission provider*. At the request of the *transmission provider*, it must take part in tests two months before the *power plant* is commissioned, or at any other date agreed upon with the *transmission provider*, to check that remote indication is working properly.

The *transmission provider* must approve the equipment used by the *power producer* to provide the required data.

Table 5 – Data required by the *transmission provider* for the Telecontrol Centre (TC) and System Control Centre (SCC) [1, 2]

	CAPACITY < 50 MW		CAPACITY ≥ 50 MW	
DATA REQUIRED	TC	SCC	TC	SCC
Total *power plant* generation in **MW and Mvar**		**Measurement** Except if impact on power system deemed negligible		**Measurement**
Generating unit circuit breaker	**State** If required for power system operation		**State**	**State** If reserve, generation rejection or LFC [3] contract
***Generating unit* disconnecting switch**	**State** If required for power system operation		**State**	**State** If reserve, generation rejection or LFC contract
***Generating unit* MW, Mvar, kV and A**	**Measurement** If required for local power system operation		**Measurement**	**Measurement** If reserve, generation rejection or LFC contract
Tie breaker	**State** Except if impact on power system deemed negligible		**State**	**State** If connected to line under SCC responsibility
***Point of interconnection* MW, Mvar, kV and A**	**Measurement** Except if impact on power system deemed negligible		**Measurement**	**Measurement** If connected to line under SCC responsibility
Water level (fore- and tailbay)				If reserve, generation rejection or LFC contract
Generation rejection, LFC – other special protection systems			If controlled, **status, measurement and control** signals transmitted To be specified, if applicable	If controlled, **status, measurement and control** signals transmitted To be specified, if applicable
Acquisition unit	**State**		**State**	**State**
Telephone link (voice)	[4]		[4]	
Breaker or disconnecting switch for the station service supply point			**State**	
Status and alarm signals	**State**		**State**	
Stabilizer [6]			**State** If applicable	**State** If applicable

1 – Requirements for remote control of the *power plant* are not included, nor those for power dispatch.
2 – Information for the SCC may go through a TC.
3 – Load-frequency control
4 – Link to contact the *power plant* operator 24/24 x 7/7 (directly without dialing, e-mail or voice mailbox)
5 – Certain signals or alarms may be required to indicate the state of tone units or the operation of protections (such as that for backup protection) that can affect the *transmission system*.
6 – Indication of stabilizer status is required whenever one is installed (see Section 5.3.2).

8.4 Telecommunication systems for operations functions

The *transmission provider* supplies, installs and maintains the telecommunication equipment needed to transmit from *power producer facilities* data enabling it to operate the *transmission system* effectively.

Figure 4 in Section 7.6 shows the junction point between the Hydro-Québec or third-party telecommunication network and *power producer* equipment. That point is generally located at the junction box connecting telecommunication equipment (at the end of the link) to *power producer* equipment used for data acquisition and remote indication.

The equipment to install, interface points and other characteristics relevant to providing the required services will be specified to the *power producer* at the *facilities study* or engineering study stage.

The *power producer* must provide adequate secure space for installing all necessary equipment, and must install junction boxes and ductwork.

9. *Modifications* to *Power Producer Facilities*

The *power producer* cannot make *modifications* to its *facilities* before the *transmission provider* has assessed the impact on the *transmission system*. To enable this, the *power producer* must submit to the *transmission provider* all relevant information regarding intended *modifications*. Those *modifications* must be coordinated with any on the *transmission system*.

10. Verification by the *transmission provider*

The *transmission provider* shall be authorized to verify that systems and equipment that the *power producer* has installed to meet *transmission provider* requirements are working properly, including the settings for protection systems, speed governors, voltage regulators and stabilizer circuits installed in the *power producer facilities*, data transmission systems, etc.

11. Verification by the *Power Producer*

The *power producer* must make all necessary verifications to demonstrate that its *facilities* comply with *transmission provider* requirements, and with *NPCC* and *NERC* requirements, where applicable.

Two types of verifications are required:

a) Initial verifications

At startup or following a *modification* to an existing *power plant*, the *power producer* must verify that its *facilities* meet *transmission provider* requirements and achieve stated levels of performance.

b) Periodical verifications

At intervals specified by the *transmission provider*, the *power producer* must verify that the characteristics and performance of its *facilities* have remained unchanged.

Such verifications are to ensure that information submitted to the *transmission provider* for steady-state and dynamic modelling of *power producer facilities* in its power system studies matches the true equipment characteristics. The verifications make it possible to measure and confirm the main characteristics of generating *facilities* (e.g., real and reactive power) and measure the dynamic performance of excitation systems, stabilizer and speed governors.

Appendix D gives details regarding validation and performance testing to be conducted for *power producer facilities*.

Verifications are made easier if the *power producer* organizes in advance the means and tools for conducting them: measurement points, ways to isolate regulation and protection systems, test signal input points, etc.

As mentioned in Section 7.4.3.2, periodic verifications include those of underfrequency trip relay settings for all 20-MW or higher *generating units*, which must be checked at least as often as prescribed in *NPCC* Document A-4, Maintenance Criteria for Bulk Power System Protection. The document is available on the *NPCC* Web site and on the *transmission provider* Web site at:

http://www.hydroquebec.com/transenergie/en/commerce/producteurs_prives.html .

12. Test Reports for *Power Producer* Equipment

Before commissioning its *power plant*, the *power producer* must submit to the *transmission provider* test and verification reports for its equipment to demonstrate that its *facilities* comply with the requirements herein.

The *power producer* must specifically give the *transmission provider* test measurements for the electrical characteristics of its equipment as given below.

- For step-up transformers supplied by the *power producer*, a copy of manufacturer test reports giving:
  - rated power and voltage, and the power at each tap
  - number of taps and regulation range
  - impedance (resistance and reactance) at each tap, including zero-sequence impedance if type tests have been run
  - exciting current (at 80%–115% of rated voltage)
  - winding connection
  - copy of each transformer's nameplate
- For generators, harmonic tests in accordance with Section 5.4.2 herein.
- For generating equipment:
  - Validation tests required by the *transmission provider* regarding generator capacity and characteristics, voltage regulator, excitation system, stabilizer and speed governor parameters, etc. will be specified to the *power producer* for each *power plant* project based on the type of generating equipment used. Such tests will be used to validate the numerical models and associated parameters that the *power producer* gives the *transmission provider* to conduct the *interconnection study* and *facilities study* under Section 3.2.1.

Appendix D gives details regarding validation and performance testing to be conducted for *power producer facilities*.

13. Event Recorders

It is essential to record relevant information when *disturbances* occur on the *transmission system* or in *facilities* connected to it, in order both to determine the performance of the grid and the *facilities*, and to analyze the nature and cause of such *disturbances*. Following *NPCC* and *NERC* requirements in this area, the *transmission provider* may require that the *power producer* incorporate into its *facilities* event recorders, fault recorders or any other instruments needed to study such events.

14. Supplementary Requirements Specific to Wind Generation

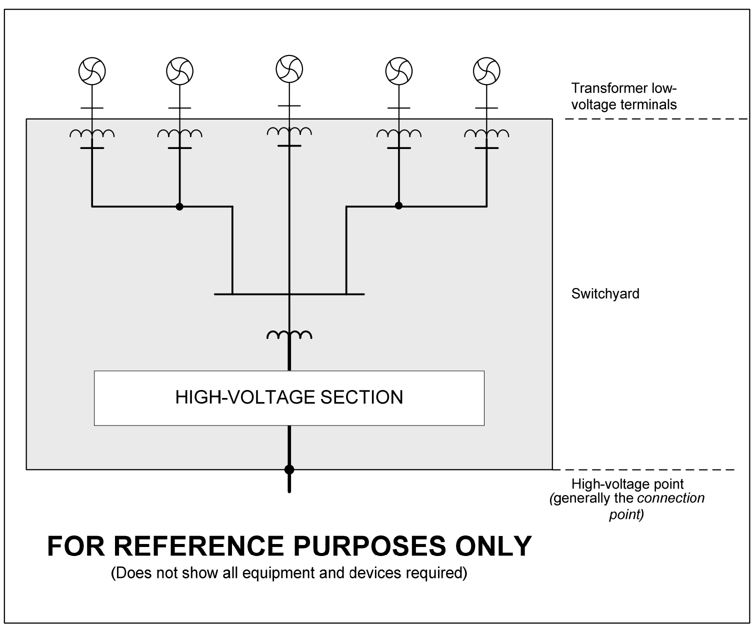
The wind power option has soared in recent years and is an area of rapidly evolving technology. Given the rapid expansion of this generating option and the impact wind generators can have on the behavior of the *transmission system*, it is important to make sure that the equipment used helps ensure that the *transmission system* functions properly.

The requirements described in this Section cover supplementary technical aspects specifically related to wind *power plants*. These requirements are in addition to those presented in preceding sections.

14.1 *Switchyard*

Figure 5 below is a schematic diagram of a *switchyard* for a wind *power plant* connected to the *transmission system*, as defined in Section 2.

Figure 5 – Boundaries of a wind *power plant switchyard*



As shown in Figure 5, the *switchyard* of a wind *power plant* comprises an initial transformation level originating at the low-voltage terminals near each wind generator, a medium-voltage system connecting to the second transformation level, one or more step-up transformers at that second level, and the high-voltage section.

14.2 Requirements for wind *power plant* response to *disturbances* on the *transmission system*

Wind *power plants* must remain in service without *tripping* as long as *transmission system* voltage and frequency remain within the steady-state ranges given in Sections 5.1 and 5.2. Furthermore, as stated in Section 4.2.2, it is essential that generating *facilities* connected to the Hydro-Québec *transmission system* remain in service without *tripping* as long as possible when *disturbances* occur on the *transmission system* so they can both help maintain grid stability and restore the voltage and frequency, and not interfere with special and conventional protection systems acting on the grid.

Wind *power plants* must be designed, built and operated in a way that they remain in service without *tripping* during the voltage and frequency variations given in the following sections.

The *power producer* can meet those requirements by adding specific equipment in the wind *power plant* (e.g., static or synchronous compensators, STATCOM).

14.2.1 Requirements during voltage variations

14.2.1.1 Requirements during undervoltage conditions (Low-voltage ride-through)

Wind *power plants* must remain in service without *tripping* (no temporary blocking is authorized) when, following a *disturbance*, the positive-sequence voltage on the high-voltage side of the *switchyard* is

- less than 1.0 p.u. but greater than or equal to 0.9 p.u.
- less than 0.9 p.u. but greater than or equal to 0.85 p.u. for less than 30 s
- less than 0.85 p.u. but greater than or equal to 0.75 p.u. for less than 2 s

Wind *power plants* must also remain in service without *tripping* during a fault occurring on the *transmission system* (including one on the high-voltage side of the *switchyard*) and for the time required to restore voltage after the fault is cleared, whether it be:

- a three-phase fault cleared in 0.15 seconds,
- a two-phase-to-ground fault or phase-to-phase fault cleared in 0.15 seconds, or

- a single-phase-to-ground fault cleared in 0.30 seconds.

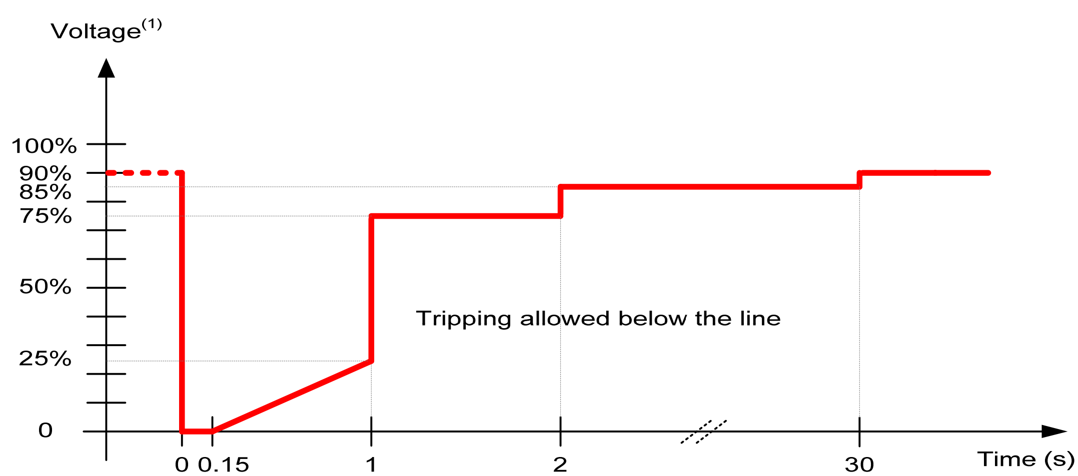
Lastly, wind *power plants* must remain in service without *tripping* during a remote fault cleared by a slow protective device (up to 45 cycles) and for the time required to restore voltage after the fault is cleared, whether the remote fault is

- a three-phase fault, if the positive-sequence voltage on the high-voltage side of the *switchyard* does not fall below 0.25 p.u.
- a two-phase-to-ground fault, if the positive-sequence voltage on the high-voltage side of the *switchyard* does not fall below 0.5 p.u.
- a phase-to-phase fault, if the positive-sequence voltage on the high-voltage side of the *switchyard* does not fall below 0.6 p.u.
- a single-phase-to-ground fault, if the positive-sequence voltage on the high-voltage side of the *switchyard* does not fall below 0.7 p.u.

Wind *power plants* must also help restore the power system to normal operating conditions (voltage and frequency) after a *disturbance*.

Figure 6 illustrates undervoltage performance requirements for wind *power plants*.

Figure 6 – Wind *power plant* low-voltage ride-through (Low Voltage Ride Through)



(1) Positive-sequence voltage on the high-voltage side of the switchyard

14.2.1.2 Requirements during overvoltage conditions

Wind *power plants* must remain in service without *tripping* at the overvoltage levels and for the durations given in Table 6.

Wind *power plants* must also help restore the power system to normal operating conditions (voltage and frequency) after the *disturbance*.

Table 6 – Overvoltage ranges vs. minimum time before wind *power plant tripping* following a *disturbance*

Overvoltage (p.u.)[1]	Minimum time
$1.0 \leq V \leq 1.10$	Extended [2]
$1.10 < V \leq 1.15$	300 seconds
$1.15 < V \leq 1.20$	30 seconds
$1.20 < V \leq 1.25$	2 seconds
$1.25 < V \leq 1.40$ [3]	0.10 second
$V > 1.40$ [3]	0.033 second

1 – Positive-sequence voltage on high-voltage side of *switchyard*
2 – Up to several hours, depending on time needed to bring grid back to normal state, i.e., within steady-state voltage range (see Section 5.1)
3 – Though temporary blocking is allowed for *facilities* using power electronics when the voltage exceeds 1.25 p.u., normal operation must resume once the voltage drops back below 1.25 p.u.

14.2.2 Requirements during frequency variations

Wind *power plants* must remain in service without *tripping* during the frequency variations given in Table 7.

Power plants must also be able to remain in service when *disturbances* occur and the system frequency varies by ±4 Hz/s.

This requirement also applies to wind *power plants* connected to the distribution system, through a *neighboring system within Québec*, a *municipal system* or the *SJBR electricity cooperative*.

Table 7 – Frequency ranges vs. minimum time before wind *power plant tripping* following a *disturbance*

Underfrequency (Hz)	Overfrequency (Hz)	Minimum time
59.4 ≤ F ≤ 60.0	60.0 ≤ F ≤ 60.6	Unlimited
58.5 ≤ F < 59.4	60.6 < F ≤ 61.5	11 minutes
57.5 ≤ F < 58.5	61.5 < F < 61.7	1.5 minutes
57.0 ≤ F < 57.5		10 seconds
56.5 ≤ F < 57.0		2 seconds
55.5 ≤ F < 56.5		0.35 second
F < 55.5	F ≥ 61.7	Instantaneous

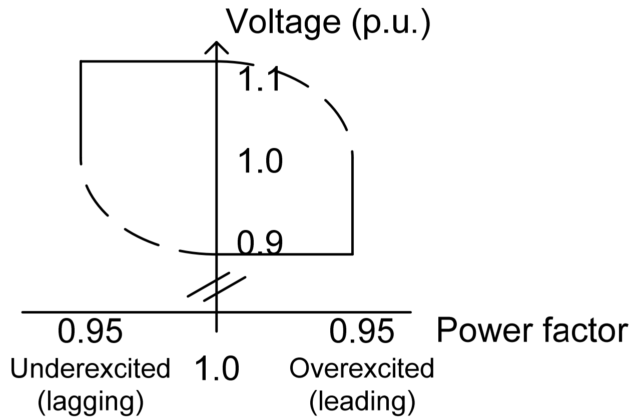
14.3 Requirements regarding voltage regulation and power factor

As mentioned in Section 5.3, voltage regulation is essential for maintaining *transmission system* stability and reliability. To be effective, a vast majority of *power plants* must help ensure this function.

Wind *power plants* must take part in regulating *transmission system* voltage continuously, dynamically and rapidly. They must be equipped with an automatic voltage regulation system that can supply or absorb reactive power corresponding to an overexcited or underexcited power factor equal to or less than 0.95 on the high-voltage side of the wind *power plant switchyard*. In addition, the *transmission provider* could require that the voltage regulation system have a permanent droop adjustable between 0% and 10%.

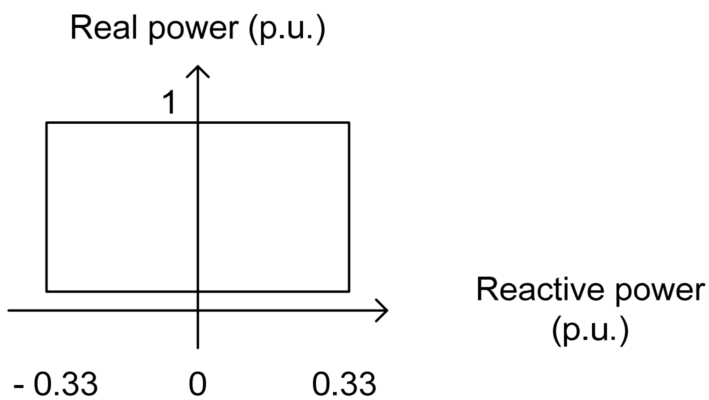
Reactive power must be available over the entire range of normal operating voltages (between 0.9 p.u. and 1.1 p.u.). At a voltage of 0.9 p.u., however, the wind *power plant* is not required to absorb reactive power corresponding to an underexcited (lagging) power factor of 0.95 p.u. It still must be able to supply reactive power corresponding to an overexcited (leading) power factor of 0.95 p.u. Similarly, at a voltage of 1.1 p.u., the wind power plant is not required to supply reactive power corresponding to an overexcited power factor of 0.95 p.u. but still must absorb reactive power corresponding to an underexcited power factor of 0.95 p.u. (see Figure 7).

Figure 7 – Reactive power available on the high-voltage side of the *switchyard* vs. voltage



Available reactive power must at least correspond to a power factor equal to 0.95 of the rated capacity of the wind generators in service, as shown in Figure 8.

Figure 8 – Reactive power available on the high-voltage side of the *switchyard* vs. real power of wind generators in service



If the *interconnection study* shows that reactive power from the wind *power plant* cannot be completely used on the *transmission system*, the *transmission provider* may accept a power factor greater than 0.95 though never exceeding 0.97.

Voltage regulation in a wind *power plant* may be assured by the wind generator itself or by other equipment (e.g., synchronous compensator or STATCOM) added to the *power plant* by the *power producer*. Voltage regulation performance of a wind *power plant* must, however, always be similar to that of a *power plant* of the same capacity equipped with conventional *synchronous generators* (see Section 5.3).

The *transmission provider* may waive the requirement for an automatic voltage regulation system in the case of a wind *power plant* with an installed capacity of less than 10 MW, especially when the short-circuit level at the *point of interconnection* is much greater than the *installed capacity* of the *power plant*. The *power producer facility* must then supply sufficient reactive power to keep the power factor at 1.0 on the high-voltage side of the *switchyard*.

14.4 Frequency control requirements (inertial response)

Wind *power plants* with a rated output greater than 10 MW must be equipped with a frequency control system. The system must be continuously in service but only act during major frequency deviations. It will not be used for steady-state frequency control.

The purpose of the system is to enable wind *power plants* to help restore system frequency and thus maintain the present level of *transmission system* performance during major *disturbances*.

To achieve this, the system must reduce large, short-duration frequency deviations at least as much as does the inertial response of a conventional *synchronous generator* whose inertia (H) equals 3.5 s. This target performance is met, for instance, when the system varies the real power dynamically and rapidly by at least 5% for about 10 s when a large, short-duration frequency deviation occurs on the power system.

14.5 Protection system requirements

As specified in Section 14.2, wind *power plants* connected to the Hydro-Québec *transmission system* must remain in service without *tripping* for as long as possible when a *disturbance* occurs.

Systems protecting *power producer facilities* must be selective enough to avoid inadvertent *tripping* when such *disturbances* occur. More specifically, no protection must trip *facilities*, directly or indirectly, for the voltage and frequency variations given in Sections 14.2.1 and 14.2.2.

14.5.1 Voltage protection

Voltage protection comprises an undervoltage function and an overvoltage function. Such protection must be selective enough to avoid inadvertent *tripping* of *facilities* when *disturbances* occur.

More specifically, voltage protection must meet Section 14.2.1 requirements, which set minimum time-lags that voltage protection must meet. Referring to Table 6, for instance, overvoltage protection with an operating threshold set to a voltage of 1.17 p.u. must have a minimum time-lag of 30 seconds.

Voltage protection must be coordinated with other existing protection systems and initiate *tripping* of the *power plant*, when required, to avoid its operation under unacceptable voltage conditions.

Note that it is not necessary to have relays for each of the values in Table 6 (see Section 14.2.1).

14.5.2 Frequency protection

Frequency protection comprises an underfrequency function and an overfrequency function. Such protection must be set to sufficiently selective thresholds and time-lags to avoid inadvertent *tripping* of *facilities* when *disturbances* occur. Such protection settings must in no instance interfere with the means implemented by the *transmission provider* to restore power system frequency after a *disturbance*.

More specifically, frequency protection must meet Section 14.2.2 requirements and the minimum time-lags in Table 7 for the various ranges of frequency deviation. Referring to Table 7, for instance, frequency protection with an operating threshold set in the frequency range $58.5 \leq F < 59.4$ must have a minimum time-lag of 11 minutes.

This requirement also applies to *power plants* connected to the *transmission system* through the distribution system, a *neighboring system within Québec*, a *municipal system* or the *SJBR electricity cooperative*.

Power producers may use more sensitive underfrequency protection settings, provided they demonstrate to the *transmission provider* that automatic load-shedding agreements have been signed with customers to offset loss of *power plant* production should underfrequency protection trip the *power plant*.

Frequency protection must be coordinated with other existing protection systems and initiate *tripping* of the *power plant*, when required, to avoid its operation under unacceptable frequency conditions.

Note that it is not necessary to have a relay for each of the values in Table 7 (Section 14.2.2).

14.6 Data requirements for *transmission system* operation

As stated in Section 8.3, the *transmission provider* requires real-time data from each *power plant* for effective operation of the Hydro-Québec *transmission system*. This data must be provided in a form compatible with *transmission provider* equipment. The minimal data required is given in Section 8.3, Table 5.

Note that wind *power plants* are also required to provide the following meteorological data:[4]

- Wind speed and direction
- Dry-bulb temperature
- Wet-bulb temperature
- Dew point
- Type of precipitation
- Atmospheric pressure

Power producers must equip their *facilities* with all sensors needed to transmit the required data to the *transmission provider*. At the request of the *transmission provider*, they must take part in tests two months before the *power plant* is commissioned or at any other date agreed to with the *transmission provider* to check that data acquisition is working properly.

The equipment used by *power producers* to provide the required data to the *transmission provider* must be accepted by the latter.

14.7 Requirements regarding technical information to be submitted to the *transmission provider* for *transmission system* planning

As specified in Section 3.2.1, the *power producer* must submit the information listed in Appendix A herein to the *transmission provider* so it can conduct studies to assess the impact of connecting the *power producer*'s *power plant*.

In particular, the *power producer* must provide detailed models of the wind *power plant* based on IEEE models, as well as associated generator and converter parameters. The models must be compatible with Siemens PTI's PSS/E software, which the *transmission provider* uses for its dynamics studies.

4 Acquisition rate: Wind data – 30 seconds
Temperature and pressure data – 10 minutes

If no IEEE model is available, the *power producer* must provide a complete black-box model, including relevant technical documentation, block diagrams, data and parameters. The model must allow all *power plant* wind generators to be represented as a single generator and must be functional across its entire range of real and reactive power. The model must also be compatible with PSS/E, used by the *transmission provider* for dynamics studies, and must be able to work with a time step exceeding 4 ms.

If a black-box model is used, the *power producer* must provide compliance test results demonstrating that it behaves like the real wind generator.

Given that technology used in wind *power plants* is diverse and rapidly evolving, the *power producer* must submit to the *transmission provider* test results demonstrating that its wind generator meets the voltage and frequency requirements described in Sections 14.2.1 and 14.2.2 herein.

If the wind generator behavior does not conform to the model, the *power producer* must assume any additional costs for interconnection with the *transmission system*.

If voltage regulation in the wind *power plant* is achieved using additional compensation equipment in the *switchyard*, the *power producer* must provide detailed models of that equipment based on standard IEEE models, as well as associated generator and converter parameters. The models must be compatible with Siemens PTI's PSS/E software, which the *transmission provider* uses for its studies of dynamic response.

Besides the information required in Appendix A, the *power producer* must submit wind generator oscillation characteristics (e.g., natural frequency and damping) for *disturbances* of a mechanical or electrical origin.

It must also give a detailed description of the strategies used by the real power, reactive power, voltage and speed control systems under the operating conditions set out in Sections 5.1 and 5.2 herein.

The *transmission provider* also requires that it be sent in the form of an EMPT model the information and data needed to conduct studies of electromagnetic phenomena, as specified in Appendix B herein.

The EMTP model must be submitted no later than six month after the winning project(s) are announced under a call for tenders by the *distributor*. For projects without tendering, the model must be submitted to the *transmission provider* when the *interconnection study* agreement is signed.

14.8 Requirements for maximum up- and down-ramp rates

Wind *power plants* must be designed and built to comply with the following maximum ramp rates when up-ramping or down-ramping output:

- ramp up in an adjustable 2 to 60 minutes from 0 MW (stopped) to Pmax (maximum *power plant* output)
- ramp down in an adjustable 2 to 60 minutes from Pmax (maximum *power plant* output) to 0 MW (stopped)

This requirement is to avoid excessive loss of wind generation at times in the day when the load is rising rapidly and an excessive rise in wind generation at other times in the day when the load is falling rapidly.

As it gains experience over the years, the *transmission provider* will readjust ramping requirements within this range for secure power system operation.

14.9 Requirements for wind generator shutdowns when very cold weather or high winds are forecast

Wind *power plants* must be designed and built to gradually shut down over a minimum 1 to 4 hours when forecasts call for cold temperatures or high winds enough to entail complete wind generators shutdown.

As it gains experience over the years, the *transmission provider* will readjust minimum time requirements within this range for secure power system operation.

14.10 Requirements for a stabilizer

Wind *power plants* must be designed and built so they can be equipped with a stabilizer.

Wind *power plants* connected to the Hydro-Québec *transmission system* must have stable behavior so they can help maintain grid stability and restore voltage and frequency when *disturbances* occur. If this is not the case, the *transmission provider* may require that the *power producer facilities* be equipped with a stabilizer. The stabilizer will then be designed jointly by the *transmission provider* and the manufacturer.

14.11 Requirements for limiting real power

Given *transmission system* operating constraints and requirements, the *transmission provider* may require that the *power producer facilities* be equipped with a control system responding to a command to limit real power and other commands.

14.12 Verification by the *power producer*

As specified in sections 11 and 12, the *power producer* must make all necessary verifications to demonstrate that its *facilities* comply with *transmission provider* requirements, and with NPCC and NERC requirements, where applicable.

Appendix D gives details regarding validation and performance testing to be conducted for *power producer facilities*.

Appendix A

Technical Information Required by the *Transmission Provider* for its *Interconnection Study*

Remarks

- The *power producer* is responsible for the validity of information (data, models and associated parameters) that it or its supplier submits to the *transmission provider* so that the latter can conduct the studies required to assess the impact of connecting the *power plant* to the *transmission system*. If *power producer facilities* do not behave according to the models and parameters submitted, the *transmission provider* may, if needed, make a new cost estimate for connecting the *power plant* to the *transmission system*.

- As a member of various bodies responsible for power system reliability (*NPCC*, *NERC*), the *transmission provider* may be asked to share with its counterparts information collected during projects covered by an interconnection agreement between the *power producer* and *transmission provider*.

1. Scheduled commissioning date

2. Site schema for *power producer facilities*

3. General information about *power producer facilities*

- type of generation (hydro-, thermal, wind power, etc.)
- installed capacity, anticipated capacity at annual peak load and projected ultimate capacity
- number of *generating units*

4. Characteristics of *power producer* equipment
(data in p.u. bases of equipment MVA)

- *Synchronous generators*:
  - type (round rotor/salient pole)
  - damper winding (connection method)
  - design ambient temperature °C
  - temperature rise at rated power °C

- coolant temperature °C
- rated capacity and voltage
- rated power factor in over-excited and under-excited modes
- unsaturated direct-axis synchronous reactance (Xd)
- unsaturated quadrature-axis synchronous reactance (Xqi)
- direct-axis transient reactance – unsaturated (X’di) and saturated (X’dv)
- quadrature-axis transient reactance – unsaturated (X’qi) and saturated (X’qv)
- direct-axis subtransient reactance – unsaturated (X"di) and saturated (X"dv)
- quadrature-axis subtransient reactance – unsaturated (X"qi) and saturated (X"qv)
- positive-sequence leakage reactance (X_1)
- negative-sequence reactance (X_2)
- time constants T’do (and corresponding temperature in °C), T’qo, T"do and T"qo
- armature resistance, by phase (Ra) and corresponding temperature in °C
- stator forward resistance (R1) at 60 Hz and corresponding temperature in °C
- saturation curve of generators to calculate parameters and factors needed in saturation modeling (Sgu, Sgl, Eu and El)
- inertia constant H (for each *generating unit*, with and without turbine)

• *Asynchronous generators:*
  - design ambient temperature
  - temperature rise at rated capacity
  - coolant temperature (where applicable)
  - rated capacity and voltage
  - power factor at 100%, 75% and 50% of rated capacity
  - stator leakage reactance (Xs)
  - stator resistance (Rs)
  - rotor leakage reactance (Xr)
  - rotor resistance (Rr)
  - magnetizing reactance (Xm)
  - locked rotor reactance (Xlr)
  - open-circuit reactance (Xo)
  - time constant T’do
  - inertia constant H (for each *generating unit*)
  - torque-slip curve
  - slip at rated capacity

- Voltage regulator, excitation system and stabilizer:
  - detailed model and associated parameters based on a standard IEEE model (IEEE 421.5 IEEE Recommended Practice for Excitation System Models for Power System Stability Studies) or, if the IEEE model is not available
  - model that the *transmission provider* can use in its dynamic simulation studies with Siemens PTI's PSS/E (Power System Simulator) software and associated parameters
- Turbine and speed governor:
  - detailed model and associated parameters based on a standard IEEE model ("Dynamic Models for Steam and Hydro Turbines in Power System Studies", IEEE Transaction on Power Apparatus and System, Vol. PAS-92, pp. 1904–1915, 1973.)

    ("Hydraulic Turbine and Turbine Control Models for System Dynamic Studies", IEEE Transactions on Power Systems, Vol. 7, No. 1, pp. 167-179, February 1992.)

    ("Dynamic Models for Combined Cycle Plants in Power System Studies", IEEE 94 WM 185-9 PWRS, "Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies") or, if an IEEE model is not available,
  - model that the *transmission provider* can use in its dynamic simulation studies with PSS/E and associated parameters
- Wind *power plants*:
  - Detailed models of the wind *power plant* based on IEEE models, as well as relevant generator and converter parameters. The models must be compatible with PSS/E software, which the *transmission provider* uses for dynamics studies.
  - If no IEEE model is available, the *power producer* must provide a complete black-box model, including relevant technical documentation, block diagrams, data and parameters. The model must allow all *power plant* wind generators to be represented as a single generator and must be functional across its entire range of real and reactive power. The model must also be compatible with PSS/E, used by the *transmission provider* for dynamics studies and must be able to work with a time step exceeding 4 ms. If the *power producer* provides a black-box model and wind generator behavior does not conform to the model, the *power producer* must pay any additional expense that may be incurred to connect its *power plant* to the *transmission system*. If voltage regulation in the wind *power plant* is achieved using additional compensation equipment in the *switchyard*, the *power producer* must provide detailed models of that equipment based on standard IEEE models, as well as associated generator and converter parameters. The

models must be compatible with Siemens PTI's PSS/E software, which the *transmission provider* uses for its studies of dynamic response.

- Step-up transformers (when supplied by the *power producer*):
  - number
  - rated power and voltage
  - power with corresponding cooling method
  - positive- and zero-sequence impedance
  - winding resistance
  - coupling (i.e., winding connection)
  - number of taps and regulation range
  - exciting current (at 80%–115% of rated voltage)
- Tie line (when supplied by the *power producer*):
  - type:
    - single- or double-circuit
    - overhead or underground
  - positive- and zero-sequence impedances (R, X, B)
  - ampacity
- *Breakers:*
  - main characteristics in voltage and current
  - insulation levels
  - interrupting capacity
- Surge arresters:
  - type
  - ratings
  - protection characteristics

5. Single-line diagram of the *power producer*'s planned *facility*

Schematic diagram showing power transformers, the position of switchgear and its operating mode (NO/NC), and the position of instrument transformers, surge arresters and breakers.

It is recommended to include a preliminary control and protection schematic.

6. Annual generation profile planned by the *power producer*

Power plant capacity factor and mean monthly value of energy (GWh) and power for a typical year.

Appendix B

Information Required by the *Transmission Provider* for Wind *Power Plant* Modeling Using EMTPWorks

In order for the *transmission provider* to conduct the transient-state studies essential for a detailed analysis of how the Hydro-Québec system will respond with the wind *power plant* operating, the *power producer* must provide, or ensure that its suppliers provide, a detailed model representing the transient response of the following main components of the wind *power plant*: wind generators and related power equipment such as converters equipped with controls (e.g., SVC and STATCOM). It must be possible to use the unmodified model with EMTPWorks©.

The detailed model must meet the requirements below.

- It must be accompanied by detailed technical documentation giving modeling assumptions, describing components and control systems modeled, and covering test results demonstrating that it behaves like the real equipment. Limits to using the model must be clearly indicated.
- It must be possible to modify in the model the various settings and parameters that the *transmission provider* can modify on the actual equipment (e.g., voltage regulator gain). The documentation must explain the effect of such settings and indicate their limits.
- The wind generator model must include detailed modeling of the rotating machine, with the rotor and blades represented using a multimass model. Blades must be represented by their aerodynamic equivalent under varying wind conditions, including variable pitch where applicable. The wind generator model must be functional across its entire range of real and reactive power, and must be designed to represent all wind generators in a wind farm by a single model of higher capacity. Depending on the wind turbine technology used and the effect of wind generator behavior seen from the grid, certain approximations may be made subject to prior agreement with the *transmission provider*.
- If the equipment modeled uses power electronics, the model must have a detailed representation of converters, including controllers and the physical limits of components.

- If the wind generator, the related power equipment or the wind *power plant* is equipped with filters or capacitor banks, they and their control logic must be represented. This control logic must also be documented.
- The model must adequately represent harmonics (including subharmonics and interharmonics) produced by a wind generator or related power equipment, and do so over the equipment's entire operating range of real and reactive power.
- The model must provide an accurate representation of the response of the wind generator or related power equipment during and after *disturbances* (current, voltage and dynamic behaviour), including the effect of control and protection systems on the behavior of the equipment or wind farm. Blocking of power electronic components or operation of crowbar protection must be represented in addition to the effect of all voltage regulators with a time constant of less than 2 seconds, including the voltage regulation systems and power factor at the *point of interconnection*.

The EMTP model must be completed and submitted to the *transmission provider* no later than six months after the winning project(s) are announced under a call for tenders by the *distributor*. For projects without tendering, the model must be submitted to the *transmission provider* when the *interconnection study* agreement is signed.

Appendix C

Information Required in *Power Producer Facility* Protection Studies

The *power producer* must submit to the *transmission provider* a study of the protection systems in its *facilities*. The study, conducted by an engineer, must include the information listed in this Appendix. It will enable the *transmission provider* to determine whether the protection systems installed at the *power plant* meet requirements for protecting the *transmission system*.

Section 1 – Introduction

- Brief description of site, project and Hydro-Québec *transmission system*
- Distinctive project features (added protections, specific instructions, etc.)
- Possible future expansion projects (adding capacity)

Section 2 – Characteristics of *power producer facilities*

- Single-line diagram of *power producer facilities*
- Electrical characteristics of generating equipment and protection systems:
  - *synchronous* or *asynchronous generators*
  - converters (if any)
  - transformers
  - breakers
  - grounding transformer impedance or neutral reactor
  - protective relays
  - instrument transformers for protection
  - excitation system
  - tie line

Section 3 – Short-circuit study

- Calculations for three-phase, two-phase, two-phase-to-ground, and single-phase-to-ground faults with and without a fault impedance. For high-impedance faults, the fault resistance used must be Rf = 10 Ω and Z_0 = 3 Rf = 30 Ω.
  - at the high-voltage busbar of the *power plant*
  - at the low-voltage busbar of the *power plant*
  - at busbar(s) of associated Hydro-Québec substation(s)
  - on the grid side of the *tie breaker* (if it is far from the *power plant*)

Fault calculations must factor in:

- the contribution of the Hydro-Québec *transmission system* and minimum and maximum *power plant* contributions
- the contribution of the *power plant* alone

Section 4 – Relay settings and coordination curves

- Table showing proposed settings for relays protecting the Hydro-Québec *transmission system* and their trip time for faults studied
- Protection coordination times or curves
- Control (or logic) and protection schematics

Appendix D

Requirements Regarding the Verification and Validation of *Power Producer* Models and Equipment

Table of Contents

Purpose and scope

This appendix gives details on *transmission provider* technical requirements for verifying *power producer facilities* under sections 11, 12 and 14.2 of the main document.[5] This appendix thus covers the validation testing required to demonstrate that *power producer facilities* meet *transmission provider* requirements and those of *NPCC* and *NERC*. It comprises the two sections below, based on the type of generating equipment.

1.0 Conventional generation: hydroelectric or thermal generation by means of synchronous or asynchronous machines with no converter

2.0 Wind generation or other emerging generating options (Section 1.2, paragraph B-4 of the main document)

Validation and performance testing is crucial for the *transmission provider* to characterize the dynamic performance of generating equipment and to develop simulation models for stability studies. The accuracy of models has a major impact on estimated capital spending for transmission, on the evaluation of transmission capacity, and on the development of operating strategies for the power system and generating equipment. Accurate simulation models are also crucial to determine what settings ensure optimal performance of both equipment and the power system.

This appendix specifies the scope of initial verification and periodic verification.

- **Initial verification**

  During *power plant* startup or following *modification* of an existing *power plant*, the *power producer* must verify that its *facilities* meet *transmission provider* requirements and achieve the required level of performance.

- **Periodic verification**

  At intervals specified by the *transmission provider*, the *power producer* must verify that its *facilities* have conserved their characteristics and have maintained their level of performance.

[5] Note that "main document" is used herein to denote the latest version of the "Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Québec Transmission System" of which this appendix is a part.

1.0 Conventional generation

This first section covers conventional equipment, such as synchronous or asynchronous generators driven by hydraulic or thermal turbines. Such technology is considered mature, and is thoroughly covered in the literature and guides. The *power producer* must verify and validate items as required by the *transmission provider* and produce a report based on the standards and methods described below.

Requirements entail testing to validate the characteristics and dynamic performance of excitation systems, power system stabilizers and speed governors in line with forthcoming *NERC* reliability standards MOD-026-1 – Verification of Models and Data for Generator Excitation System Functions, and MOD-027-1 – Verification of Generator Unit Frequency Response. Similarly, to validate the maximum real and reactive power capability of generating equipment, this document refers to the requirements of *NERC* reliability standards MOD-024-1 and MOD-025-1, and to NPCC reliability reference directories #9, Generator Gross and Net Real Power Capability, and #10, Generator Gross and Net Reactive Power Capability.

This section covers initial and periodic verification of *power producer facilities* and the various reports and documents to be delivered.

1.1 Validation of synchronous or asynchronous generator models and parameters

The generator models and parameters requested by the *transmission provider* in Appendix A to the main document are essential to properly simulate *transmission system* behavior and to ensure its transmission capacity.

Initial verification

- The *power producer* must perform tests to validate the parameters and models that it gave the *transmission provider* for power system study purposes under Section 3.2.1 and Appendix A of the main document.
- The *transmission provider* must agree to the parameter validation method. For synchronous generators, the validation method must be that specified in IEEE Standard 115. For asynchronous generators, the recommended reference is IEEE Standard 112 but other standards may be considered on a case-by-case basis.
- Parameter validation is a type test (i.e., is performed on one generator of each model at the *power plant*) except for open-circuit characteristics (up to 1.2 p.u. of the stator voltage) and short-circuit characteristics, which must be determined by testing each *power plant* generator.

Periodic verification

- No periodic verification is requested.

1.2 Validation of voltage regulation system parameters and models

Voltage regulation system testing validates parameters and models used in *transmission provider* stability studies and settings tuning studies. Tuning settings has a major impact on both power system behavior and on the security of *power producer* and *transmission provider* equipment.

Initial verification

- All voltage regulation systems must be verified.
- The *power producer* must demonstrate that *transmission provider* requirements in Section 5.3 of the main document are met.
- The *power producer* must update voltage regulator and excitation system models and block diagrams submitted to the *transmission provider* for conducting power system studies under Section 3.2.1 of the main document. The *power producer* must also apply the settings established by the *transmission provider*.
- Simulation models must faithfully represent the dynamic response of *generating units* during voltage and frequency variations in the ranges given in Section 4, tables 1, 2 and 3 of the main document. Tests are needed to characterize all functions of the regulation system: automatic voltage regulator, underexcitation limiter, overexcitation limiter, V/Hz limiter, reactive current compensation, stabilizer, firing circuit of bridges, sensors, etc.
- The *transmission provider* must approve the validation method; IEEE 412.2 being a recognized reference guide on validation parameters for voltage regulation systems.
- Minimally, the following tests must be performed: with the *generating unit* not synchronized, a voltage set point step response; with the *generating unit* synchronized, voltage set point step responses to validate excitation system gain with and without a stabilizer, step responses to verify positive and negative ceiling voltages of the excitation system and immediate response of the excitation system, step responses with and without a stabilizer to validate overexcitation and underexcitation limiters, and short-duration (voltage pulse) step responses with a stabilizer.
- The tests above are type tests performed on one *generating unit* of each design at the *power plant*, except for short-duration step response with a stabilizer, which must be performed on all *power plant generating units*.

- The *power producer* must show that the model is adequate by demonstrating that a numerical simulation gives results closely matching test results.
- Measurement points: For each test, at least stator voltages and currents for the three phases must be recorded, as well as field voltage and current, and the stabilizer output signal. The *power producer* must make sure that the excitation system has the analog or digital inputs needed to run the required tests (e.g., to measure step responses). The excitation system must have the analog inputs and outputs needed to determine and characterize the transfer functions of the various block diagrams. The *power producer* must ensure at the design stage that measurement points will be readily accessible.

Periodic verification

Every five years, at least short-duration step responses must be verified for all *power plant generating units* and the results must remain similar to those obtained during initial verification of the *generating units*. If periodic test results are not similar, the *power producer* must take the necessary corrective action.

1.3 Validation of speed governor system parameters and models

Speed governor system tests validate parameters and models used in *transmission provider* stability studies and settings tuning studies. Tuning settings has a major impact on both power system behavior and on the security of *power producer* and *transmission provider* equipment. Power system frequency behavior and stability depend on proper governing of *generating unit* speed, which also has a direct impact on customer power quality.

Initial verification

- All speed governor systems must be verified.
- The *power producer* must demonstrate that its *facilities* comply with *transmission provider* requirements in Section 5.3 of the main document.
- The *power producer* must update speed governor models and block diagrams submitted earlier to the *transmission provider* for conducting its studies under Section 3.2.1 of the main document. The *power producer* must also apply the settings given by the *transmission provider*.
- Simulation models must faithfully represent the dynamic response of *generating units* during frequency variations in the ranges given in Section 4, Table 2 of the main document. Tests are needed to characterize all functions of the speed governor system.
- The *transmission provider* must approve the validation method for the speed governor system. For hydroelectric *power plants*, the reference international

standard is IEC 60308. For gas and steam turbines, the reference used is CIGRE Technical Brochure 238.

- The following validation of parameters and models is performed by type tests on one *generating unit* of each design at the *power plant*. The *power producer* must identify speed governor mechanical components and sensor transfer functions on a block-by-block basis. Tests must be run for the various operating points within the operating range of the *generating units*. The *power producer* must perform tests to validate *generating unit* inertia constant H. After identifying blocks, frequency step responses must be measured to demonstrate that the overall model is adequate. Minimally, the following frequency step responses must be measured: with the *generating unit* not synchronized, one frequency step response; with the *generating unit* synchronized, positive frequency step responses at 10%, 50% and 90% of rated capacity, and one negative frequency step response at 90% of rated capacity.
- The positive frequency step response at 90% of rated capacity must be measured on all *power plant generating units*. The results will serve as a benchmark for periodic verification.
- The *power producer* must show that the model is adequate by demonstrating that a numerical simulation gives results closely matching test results.
- Measurement points: For each test, at least the frequency, real power and output signals for the main blocks of the speed governor system must be recorded. The *power producer* must make sure that the speed governor system has the analog or digital inputs needed to run the required tests (e.g., to measure step responses). The speed governor system must have the analog inputs and outputs needed to determine and characterize the transfer functions of the various block diagrams. The *power producer* must ensure at the design stage that measurement points will be readily accessible.

Periodic verification

Every five years, the *power producer* must at least measure the positive frequency step response at 90% of rated capacity for all *generating units* and results must remain similar to those obtained during initial verification of the *generating units*. If periodic test results are not similar, the *power producer* must take the necessary corrective action.

1.4 Harmonics

Initial verification

- The *power producer* must run validation tests in accordance with the requirements in Section 5.4 of the main document. Such tests must be run on each *generating unit* before it is synchronized. If results are unsatisfactory, the *generating unit* cannot be synchronized to the grid unless the *transmission provider* provides explicit authorization to do so.

Periodic verification

- No periodic verification is requested.

1.5 Maximum real and reactive power capability

The purpose of validation testing is to determine a *power plant*'s maximum real and reactive power capability under various operating conditions. The first step is to evaluate the *power plant*'s maximum real and reactive power by group testing all *generating units* while remaining within system operating voltage limits and meeting any power system thermal constraints. The second step is to evaluate a *power plant*'s maximum real and reactive power capability in order to confirm the rated power factor of each generator. Such a test measures the capability of generators to support transmission system voltage during a contingency such as the tripping of one or more transmission lines. This evaluation is done by testing each generator individually up to its top capability without causing a *power plant* or power system operating constraint.

Initial verification

- Initial verification consists in running the group tests and individual tests (i.e., those run on each *generating unit*) described in the Québec balancing area procedure IQ-P-001: "Vérification de la puissance active et réactive maximales des centrales de 50 MVA ou plus" [Testing of maximum real and reactive power at generating stations of 50 MVA or higher capacity], which complies with *NPCC* and *NERC* requirements, specifically the following:
  - Requirements in *NERC* reliability standards TOP-002-2, VAR-001-1 and VAR-002-1
  - Criteria in *NPCC* reliability reference directories #9, Generator Gross and Net Real Power Capability, and #10, Generator Gross and Net Reactive Power Capability

Periodic verification

- Items to be verified periodically are described in verification procedure IQ-P-001.
- For *power plants* of 50 MVA or higher capacity located in Québec, group testing is only done once per year, during the winter.
- Individual testing may be performed at any time.

1.6 Transformer data

- When the *power producer* supplies *generating unit* step-up transformers, it must submit to the *transmission provider* the results of factory type and routine tests performed on the transformers. It must also submit to the *transmission provider*, where appropriate, a description of any voltage regulation performed by on-load tap changers, including the regulation methods and associated block diagrams.

1.7 Instrumentation

Instrumentation used by the *power producer* for validation testing must have the following minimal features:

- Digital instruments to facilitate matching test results to numerical simulation results
- 16-bit precision
- Minimum of 16 channels
- Anti-aliasing filters adjustable to the sampling rate or based on the sigma-delta technique
- Sampling rate and recording time: adjustable depending on test requirements. For example, a voltage regulator step response would require sampling at 10 kHz or higher for about 30 s, while a step response to verify an overexcitation limiter may require recording for several minutes but at a sampling rate reduced to 2 kHz.

1.8 Deliverables

While it is recognized that certain validation tests may be run in the factory, most testing will be conducted on site, some tests with the *generating unit* shut down, others with it running and either synchronized or not.

- Documents and test reports must be prepared and signed by an professional engineer.
- Six months prior to the very first (factory or on-site) test, the *power producer* must submit to the *transmission provider* a comprehensive test program describing the control systems and test methods in order to obtain the parameters to test, the test location (factory or on site) and a preliminary schedule. The test program will be reviewed for approval by the *transmission provider*.
- Three months before any testing begins, the *power producer* must submit to the *transmission provider* a detailed procedure covering the following points: list of parameters verified by testing, validation method, test conditions ("on grid" or

"off grid" and initial conditions), all steps in the procedure, variables recorded, characteristics of the measurement setup and test schedule.

- The *transmission provider* reserves the right to attend certain tests or verifications performed by the *power producer* or its suppliers. The *power producer* must therefore promptly notify the *transmission provider* of any change in schedule.
- Test reports must contain a description of the systems verified and models validated (for voltage regulation and speed governing), tables giving the parameters that the *power producer* gave the *transmission provider* for the *interconnection study* and those obtained during the validation, with test results paired to numerical simulation results (for voltage regulation and speed governing). The reports must be submitted for comment to the *transmission provider*, which will have one month to respond. The submitting of the final version of test reports by the *power producer* is one prerequisite for final acceptance of the *facilities* by the *transmission provider*.
- The *power producer* must also submit the raw test data (recorder data) should the *transmission provider* so require.

2.0 Wind generation and other emerging generating options

This second section covers non-conventional generating equipment, such as that for wind generation or emerging generation options (e.g., fuel cells and photovoltaic cells).

The *power producer* is responsible for conducting the tests, the purpose of which is to verify compliance with requirements and validate simulation models. It is the *transmission provider*, however, that supplies and installs the necessary instrumentation for testing and that analyzes test results unless the *transmission provider* and *power producer* agree otherwise.

Passing such tests is one of the prerequisites for final *transmission provider* acceptance of *power plant* interconnection.

2.1 Initial verifications

Initial verification is done both by testing and by using a monitoring system.

The tests must be run by the *power producer* but the description of the tests is given by the *transmission provider*. Certain verifications are also made throughout the *power plant*'s operation using a monitoring system installed by the *transmission provider*.

Tests and methods specific to wind *power plants* are described in the document "General Validation Test Program for Wind Power Plants Connected to the Hydro-Québec Transmission System" available on the *transmission provider*'s site at:

http://www.hydroquebec.com/transenergie/en/commerce/producteurs_prives.html.

Tests are intended to verify:

- Primary voltage control
- Undervoltage response and LVRT
- Inertial response
- Secondary voltage control
- Power factor
- Maximum ramp rates

There are no specific tests for power quality in the general test program. Power quality is only validated during *power plant* operation.

Regarding other emerging generating options, the *transmission provider* will supply a description of and methods for specific tests covering such technology once it has determined specific interconnection requirements for such options.

2.2 Periodic verification

The *transmission provider* will make specific requests for periodic testing (about every five years). The *power producer* must help implement such testing by providing appropriate test conditions and by assisting the *transmission provider*, free of charge, in conducting the tests.