

# **Characteristics and target values of the voltage supplied by Hydro-Québec transmission system**

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Translated July 5, 2001

Original in French dated June 15, 1999

This document is translated from the French document entitled: *Caractéristiques et cibles de qualité de la tension fournie par le réseau de transport d'Hydro-Québec.*

In case of any difference between the English and French version, the French version shall prevail.



## Summary

The purpose of this document is to familiarize customers with the different phenomena affecting voltage quality, to describe these phenomena and to encourage customers to use this information to adequately protect their equipment and minimise the possible impact of various disturbances.

**The characteristics and target values of the voltage presented in this document are general in nature and intended for information purpose only. These figures provide the best possible indication of what to expect; they in no way, however, guarantee that a given customer in a specific zone may not experience larger variations of the voltage characteristics and a greater number of events. In no way does this document constitute an obligation or guarantee of any kind whatsoever on the part of TransÉnergie .**

The document describes, at the connection point to the high-voltage system, the principal characteristics and quality of voltage provided by the Hydro-Quebec transmission system under usual operating conditions. They do not apply in cases of *force majeure* or in other specific situations outlined in the Scope section.

The present document is partly based on practices recommended by national and international electricity supply standards and adapted to the Hydro-Quebec system.

More specifically, this document covers steady state voltage, harmonics, voltage imbalance, flicker, short interruptions, voltage dips, temporary overvoltages, frequency and voltage variations, and transient overvoltages. For certain characteristics, target values are defined with reference to standards and in terms of probability, i.e., they are applicable for a percentage of time in a specific time period. For other characteristics, however, factors such as current knowledge or standardisation, the random or external nature of disturbances, enable us to provide only a general range of values representing current knowledge on the subject.

Furthermore, in order to ensure compatibility between customer equipment and the electricity supplied, this equipment must have adequate immunity levels. Also, disturbances originating from customer equipment or installations must be below authorized emission levels, so that their cumulative effect on the system will not create an unacceptable risk of exceeding compatibility levels.

This last aspect, in relation to the control of disturbances produced by the installations of customers connected to the transmission system, falls under TransÉnergie emission limits requirements. Customers must therefore comply so that the target values presented herein may be reached.



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## Preamble

The purpose of this document is:

- to familiarize customers with the guidelines generally accepted by the international community or defined by Hydro-Québec for the different phenomena affecting voltage quality;
- to remind customers that supplied electricity is subject to interruption or disturbance;
- to encourage customers to use the information provided to adequately protect their equipment and to organize their use of electricity to minimise the possible impact of the various phenomena as necessary;
- to encourage equipment suppliers to offer the necessary options to ensure the compatibility of their equipment with the normal supply of electricity.

The voltage characteristics defined in this document are general in nature; they should not, therefore, be regarded as complete or sufficient to ensure the correct operation of an installation or a given device.

The customer must therefore consider all relevant phenomena and characteristics in their entirety to ensure the adequate integration of an installation or device in its unique environment, all in accordance with applicable standards and codes.

It is also important to note that the characteristics and target values presented in this document provide the best possible indication of what to expect; they in no way, however, guarantee that a given customer in a specific zone may not experience larger variations of the voltage characteristics and a greater number of events.

In this respect, **Hydro-Québec guarantees neither the maintenance of voltage and frequency at a stable level nor the continuity of the supply and delivery of electricity. In no case shall it be held contractually or extra-contractually liable for damage caused to property resulting from the supply or delivery of electricity or failure to supply or deliver electricity, or resulting from accidental grounding, mechanical failure on its system, any interruption of service, frequency variations or supply voltage variations.** (Bylaw 634, s.102)

Moreover, even when the system is exploited within the limits defined in this document, it is still essential that equipment or processes be designed or immunized in such a way that they are neither disturbed nor damaged by their electrical environment.

This is why **the customer must ensure the protection of property and the safety of persons wherever electricity is supplied or delivered and he is responsible for protecting himself from the consequences of any interruption in the supply or delivery of electricity and for protecting his electrical installation and apparatus from voltage variations and losses, frequency variations and accidental groundings.** (Bylaw 634, s.66)

The measuring methods referred to in these pages are relatively new. As a consequence, the pertinent measuring devices may not be widely available for a few years yet. In the meantime, available measuring devices may be used, with results treated and interpreted respecting the new methods as much as possible.

## **Context**

This document is partly based on practices recommended by national and international standards and adapted to the Hydro-Québec system. Among the standards currently used or being developed on power quality and compatibility between load and power supply, priority was given to standards issued by the International Electrotechnical Commission (IEC) as well as to standard EN50160 [ 1 ] of the European Committee for Electrotechnical Standardisation (CENELEC), both among the most advanced standards in the industry.

We should mention that as far as high voltage systems are concerned, there is no international standard defining compatibility levels as such for power quality. There are however standards defining the measurement of certain types of disturbance; and technical reports providing guidelines for planning levels that can be adapted to suit different high voltage systems.

Furthermore, voltage quality measurements will be taken in the next few years to continue to quantify the various voltage quality indices as applied to the Hydro-Québec transmission system. With these measurements then at hand, the voltage quality disturbance levels given here as indicative guidelines may be more precisely defined.

Under usual operating conditions, supply voltages are subject to variations for a number of reasons: changes of the load connected to the supply system, disturbances generated by various devices, and faults arising chiefly from external events. Characteristics may vary randomly: over time at a specific supply point, or by location at a given point in time.

Some of the phenomena affecting voltage are especially unpredictable, making it impossible to give definite values for the characteristics in question. So we must define the effect of events on these characteristics in terms of statistics and probabilities, rather than characterizing them by extreme values.

## **Compatibility of equipment and supply**

Electricity supplied at a high voltage connection point in perfect conformity to the characteristics set forth in this document cannot guarantee the satisfactory operation of equipment or processes. This guarantee may only be obtained if all equipment or processes are compatible with the power supply.

At the international level, Electromagnetic Compatibility (EMC) is defined as " the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment " [standard IEC 50 (161-01-07)].

There are two conditions necessary for electromagnetic compatibility:

- customer equipment must have immunity levels higher than the compatibility levels specified for any given phenomenon;
- disturbances emanating from customer installations or equipment must be below the system-authorized emission limits so that their cumulative effect does not involve an inadmissible risk of exceeding compatibility levels.

The standards on immunity, such as standard IEC 61000-4-11, "Voltage dips, short interruptions and voltage variations immunity tests" cover the characteristics relating to the first aspect.

The desired degree of compatibility between equipment and supply depends of course on the end use of the equipment and the consequences of incompatibility. For example, the momentary interruption of a variable speed drive and the motor it actuates can be acceptable on a ventilation system, but not so for a production line.

For each application, therefore, one must gauge the degree of immunity conferred on a piece of equipment in relation to its source of power. This immunity can be an integral feature of the equipment, but it can also be improved by the use of filters, an uninterruptible power supply, etc.

Concerning the second aspect of compatibility — disturbances generated by the installations of the customers connected to the system — these are covered by TransÉnergie authorized emission limits, and customers must be in compliance, so that target values presented herein may be reached.

## **Use of electricity**

Let us recall that at all times the customer must use electricity according to the available power limit in such a way that he does not disturb Hydro-Québec's system, hinder the supply of electricity to other customers or put Hydro-Québec representatives at risk (Bylaw 634, s.74). The customer is also liable for any damage caused to other customers or to Hydro-Québec for use of electricity not in compliance with Bylaw 634, s.74. (Bylaw 634, s.104)

## Object

The object of this document is to define and describe the values characterizing the voltage supplied by the Hydro-Québec transmission system — frequency, magnitude, symmetry of three-phase voltages and waveform — in order to provide customers with better information.

## Scope

The document describes, at the point of connection to the high voltage system, the main characteristics of the voltage quality provided by the Hydro-Québec transmission system under usual operating conditions.

It does not apply to the following situations:

- exceptional circumstances linked to external influences or events, such as extreme weather conditions, natural disasters, excessive disturbances generated by third parties, *force majeure*, explosions, accidents or breakage of machinery or equipment, interruptions due to external causes, or if public safety requires it, etc;
- islanded systems; operation after a power interruption or under provisional supply conditions during maintenance or construction work or with a view to minimising the extent and duration of a supply cut;
- non-compliance of customer installations or equipment with the relevant codes, standards or Bylaws or with the technical requirements for connection;
- non-compliance of customer installations or equipment with the authorized disturbance emission limits on the Hydro-Québec transmission system;
- non-compliance of power generating plants with the relevant standards or with the requirements for connection of generating stations to Hydro-Québec system;
- autonomous (electrical) systems (e.g.: the Magdalene Islands electrical supply system, the system on the Lower North Shore supplied by the Lake-Robertson generating station, electrical systems supplied with fossil fuel generating units or other types of autonomous generating plants in the Northern communities, etc.)
- neighbouring systems which supply Hydro-Québec customers or substations just as other parts of the Hydro-Québec system that are being supplied by these substations (Hydro-Québec substations and customers supplied by the Alcan power system, part of the Témiscamingue system not connected to the main system but inter-connected with Ontario, the Manicouagan Hydroelectric Co system, the Bryson generating station synchronized with Ontario, etc).

**The characteristics and target values of voltage quality presented in this document are general in nature and intended for information purposes only. These figures provide the best possible indication of what to expect; they in no way, however, guarantee that a given customer in a specific zone may not experience larger variations of the voltage characteristics and a greater number of events. In no way does this document constitute an obligation or guarantee of any kind whatsoever on the part of TransÉnergie.**

At no time can the characteristics and target values presented in these pages be construed as voiding or amending the provisions of Bylaw 634 respecting the conditions governing the supply of electricity nor serve to interpret the meaning or the scope of that Bylaw whose pertinent provisions are appended hereto. They should also not be interpreted as limits to the disturbances that customers connected to the Hydro-Québec system are allowed to generate (known as emission limits).

## **Definitions:**

For the purpose of this document, the following definitions apply:

### **Autonomous (electrical) system**

Any system for the production and distribution of electricity, independent of the main system. (Bylaw 634, s.3)

### **Compatibility**

The ability of a device or system to function satisfactorily and without introducing intolerable disturbances for other devices connected to the electrical supply system. (It is the equivalent of "Electromagnetic Compatibility " defined by the IEC).

### **Connection point to the high voltage system**

The point where the electrical supply of a given customer or substation is connected to the high voltage transmission system. This is the point where the characteristics and target values of voltage supplied at high voltage by the transmission system covered in this document are defined.

### **Cycle**

One period duration of the fundamental frequency wave of the alternating voltage of the supply system. For a frequency of 60 Hz, this duration is 1/60<sup>th</sup> of a second, that is to say 16.67 milliseconds.

### **Flicker**

Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time. [International Electrotechnical Vocabulary (50-161-08-13) ].

### **Force majeure**

Any act of God, labour conflict, act of a public enemy, war, insurrection, riot, fire, storm or flood, explosion, breakage or accident to machinery or equipment, any curtailment, order, regulation or restriction imposed by a military government or legally constituted civilian authorities, or any cause beyond Hydro-Québec's control.

### **Supply voltage frequency**

Rate of repetition of the fundamental wave of the supply voltage, measured for a specific time interval. The frequency of an alternating voltage system of public distribution is directly related to the number of revolutions of the alternators.

### **Harmonic voltages**

Sinusoidal voltages with a frequency equal to an integer multiple of the fundamental frequency of the system (60 Hz).

**High voltage**

In this document, the term refers to those parts of the transmission system whose nominal voltage between phases is 44 kV- 315 kV.

**Indicative value**

For some voltage characteristics, the current state of knowledge or standardisation, or the random or external nature of disturbances, does not enable us to define target values. The indicative values, which are then given, simply reflect current information on the subject.

**Interruption**

Power outage lasting more than 1 minute (See appendix A for service continuity index statistics).

**Islanded system**

Electrical system with one or more generating stations and loads which is temporarily disconnected from the main system following a disturbance or a switching operation.

**Main system**

The largest body of Hydro-Québec electrical supply systems linked together.

**Measurement period**

One continuous week used as a reference period during which statistics are gathered and assessed. Measurements can however be taken for more than one week if necessary.

**Neighbouring system**

System not belonging to Hydro-Québec, but which can be connected to its main system.

**Nominal system voltage**

R.M.S. voltage between phases used to designate a system. For our purposes, the nominal voltages ( $V_{nom}$ ) are established as follows: 44 kV, 49 kV, 69 kV; 120 kV; 161 kV; 230 kV and 315 kV.

**Rapid voltage changes**

Series of sudden variations or cyclic variations of the R.M.S. value of the voltage between two consecutive levels, generally caused by load changes or system switching.

**R.M.S. value**

Root-mean-square value.

**Short interruption**

Complete loss of supply voltage on all phases for a period not exceeding 1 minute.

**Steady state voltage**

R.M.S. value of the voltage evaluated over 10 minutes.

**Supply voltage**

Voltage supplied by the transmission system at the connection point to the high voltage system.

**Target value**

The target limit set for certain voltage characteristics for a specific percentage and a specific time period. These limits may occasionally be exceeded. Additionally, some high voltage target values can be exceeded when they will not cause compatibility levels to be exceeded at lower voltage levels.

**Temporary overvoltage**

Sudden increase in the R.M.S. value of the voltage on one or more phases (more than 110 % of the nominal voltage) for a duration lasting from 8 ms to 1 min.

**Transient overvoltage**

Very rapid increase in the voltage at high frequency, independent of supply voltage frequency. The overvoltage can take the form of an impulse of negative or positive polarity or of a dampened oscillation. It can be caused by commutation of loads, system switching, or lightning.

**Usual operating conditions**

Conditions enabling load demand to be met, system switching operations to be carried out and the routine clearing of faults by automatic system protection, in the absence of *force majeure*, exceptional conditions or any temporary operating conditions.

**Value defined at 95 %**

Applies to a one-week measurement period: a value defined at 95 % means that for 159.6 out of the 168 hours of one week, the measured values are below the target or indicative values defined by its characteristics. For any one-week period, a given characteristic could therefore exceed its corresponding target or indicative value for 8.4 hours.

**Voltage dip**

Sudden reduction of more than 10 % of nominal voltage on one or more phases lasting from 8 ms to 1 min.

**Voltage unbalance**

Situation where the three voltages of the three-phase system are not equal in magnitude or are not phase shifted by 120° from one another.

## CLASSIFICATION OF THE DISTURBANCES AFFECTING THE ELECTRICAL SUPPLY SYSTEM

The following general classification, provided for information purposes, makes it possible to distinguish the type and the duration of the phenomena under study here, e.g., impact on equipment, recommended methods of measurement and the nature of the values presented.

| PHENOMENA<br>(typical duration)                             | TYPE                          | PAGE | POSSIBLE<br>EFFECTS                                    | MEASUREMENT                            | VALUES   |
|---|-------------------------------|------|--|--|--|
| <b>Long duration<br/>or<br/>permanent<br/>( &gt; 1 min)</b> | • Steady state supply voltage | 7    | Overheating of electronics, motors or transformers     | RMS values over 10 minutes             | T<br>A<br>R<br>G<br>E<br>T                     |
|   | • Harmonic voltages           | 9    |  |  | RMS values over 2 hours                        |
|   | • Voltage unbalance           | 11   |  | Weighted cubic mean value over 2 hours |  |
|   | • Flicker                     | 12   | Impression of visual discomfort                        |  |  |
| <b>Long transients<br/>( &gt; ½ cycle<br/>≤ 1 minute)</b>   | • Short interruptions         | 13   | Halt of equipment                                      | Duration of interruption               | I<br>N<br>D<br>I<br>C<br>A<br>T<br>I<br>V<br>E |
|   | • Voltage dips                | 14   | Halt of industrial processes, or equipment malfunction | RMS values over 1 cycle                |  |
|   | • Temporary overvoltages      | 15   |  | Mean value over 12 cycles              | T<br>A<br>R<br>G<br>E<br>T                     |
|   | • Frequency variations        | 16   |  | RMS values over 3 seconds              |  |
|   | • Rapid voltage changes       | 17   |  |  |  |
| <b>Short Transients<br/>( ≤ ½ cycle)</b>                    | • Transient overvoltages      | 18   | Halt of industrial processes, insulation failure       | Crest value and waveform               | INDICA-<br>TIVE                                |

# STEADY STATE VOLTAGE

## **Description**

Steady state supply voltage is defined by a range of values characterizing the possible variations of the R.M.S. value. This is fundamental for the operation of electrical equipment.

## **Causes of variations**

In an electrical supply system, the steady state voltage magnitude depends on system design characteristics, load changes and other changes to which the system is subjected. It is common practice to correct steady state voltage at various points on the system, for example, using automatic tap changers at the transformer substations.

## **Method of evaluation**

Steady state voltage variations are evaluated by taking the quadratic mean of the R.M.S. value variations in relation to nominal voltage over 10-minute time integration intervals. The target values presented on the following page must be compared, for the applicable case, with the value corresponding to 95% or 99% of the results obtained over a one-week measurement period, excluding interruptions. Measurement methods are described in reference [ 2 ].

## Target values

The range of steady state supply voltage target values under usual operating conditions is defined according to standard CSA C235-83 [3] for nominal voltage levels ( $V_{nom}$ ) between 44 kV and 49 kV. For voltage levels higher than 50 kV, the range is established by Hydro-Québec bylaw 634.

### Target values of steady state supply voltages

| VOLTAGE LEVELS   | MINIMUM VALUES                             | MAXIMUM VALUES   |
|------------------|--|------------------|
|                  | USUAL OPERATING CONDITIONS<br>(95% values) |                  |
| 44kV and 49.2 kV | $V_{nom} - 6 \%$                           | $V_{nom} + 6 \%$ |

| VOLTAGE LEVELS      | MINIMUM VALUES                             | MAXIMUM VALUES    |
|---------------------|--|-------------------|
|                     | USUAL OPERATING CONDITIONS<br>(99% values) |                   |
| Higher than 50 kV * | $V_{nom} - 10 \%$                          | $V_{nom} + 10 \%$ |

Note\*: For voltages higher than 50 kV, nominal voltages ( $V_{nom}$ ) are established as follows: 69 kV; 120 kV; 161 kV; 230 kV and 315 kV.

## HARMONIC VOLTAGES

### Description

Harmonics are sinusoidal voltages or currents whose frequencies are integer multiple of the fundamental frequency (60 Hz). The present definition covers long duration harmonics, excluding isolated transient phenomena.

### Causes

Harmonics are caused by devices whose voltage/current characteristic is not linear, e.g., electronic power converters for motor drives, rectifiers used for electrolysis, arc furnaces, etc.

### Method of evaluation

Harmonic voltages are individually measured by magnitude ( $U_n$ ), generally expressed as a percentage magnitude of the fundamental voltage ( $U_1$ )\*. The individual harmonic factor ( $D_n$ ) and the total harmonic factor ( $D$ ) are calculated as follows:

individual harmonic factor: 
$$D_n = \frac{U_n}{U_1} \cdot 100\% \quad (n : \text{harmonic order})$$

total harmonic factor: 
$$D = \sqrt{\sum_{n=2}^N \left(\frac{U_n}{U_1}\right)^2} \cdot 100\%$$

Unless specific conditions apply,  $N$  is usually equal to 50.

Individual harmonic factors ( $D_n$ ) and the total harmonic factor ( $D$ ) correspond to the harmonic voltage R.M.S. value measured over 10-minute integration time intervals. Harmonic voltage levels are evaluated excluding periods with fast transients, voltage dips, temporary overvoltages, short interruptions and interruptions, or periods when three-phase voltage falls below 50% of nominal voltage. The measurement method is described in reference [ 2 ].

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\* Note: Harmonic factors can also be expressed relative to a fixed reference voltage such as nominal voltage, rather than relative to the fundamental voltage. Evaluation of harmonic factors relative to a fixed reference makes it possible to find the absolute levels of harmonics even if the fundamental component fluctuates.

## Target values

The values set for high voltage systems are the planning-level indicative values presented in the international report IEC 61000-3-6 [4], except for some harmonics (e.g.: order 15, 21) whose values have been adjusted considering North American systems characteristics. These values have been established to co-ordinate levels of disturbance emission between the different voltage levels. Consequently, higher values may occasionally appear on the transmission system if they do not cause compatibility levels to be exceeded on the system at lower voltage levels.

Individual harmonic voltage factors ( $D_n$ ) and the total harmonic factor ( $D$ ) should be kept below the target values shown in the table below, 95% of the time over a one-week measurement period under usual operating conditions.

### Target values for harmonic factors at high voltage (HV)

| ODD HARMONICS |                                | EVEN HARMONICS                 |                                |
|---------------|--------------------------------|--------------------------------|--------------------------------|
| Order (n)     | TARGET VALUES AT HV ( $D_n$ %) | Order (n)                      | TARGET VALUES AT HV ( $D_n$ %) |
| 3             | 2                              | 2                              | 1.5                            |
| 5             | 2                              | 4                              | 1                              |
| 7             | 2                              | 6                              | 0.5                            |
| 9             | 1                              | 8                              | 0.4                            |
| 11            | 1.5                            | 10                             | 0.4                            |
| 13            | 1.5                            | $\geq 12$                      | 0.3                            |
| 15            | 0.75                           |                                |                                |
| 17            | 1                              |                                |                                |
| 19            | 1                              |                                |                                |
| 21            | 0.5                            | TOTAL HARMONIC FACTOR ( $D$ %) |                                |
| 23            | 0.7                            |                                |                                |
| 25            | 0.7                            | n = 2 to 50                    | 3 %                            |
| > 25          | $0.2 + (0.5 \times 25/n)$      |                                |                                |

*Note* : Harmonics levels higher than those shown may be recorded following “uncontrollable events”, such as geomagnetic storms.

# VOLTAGE UNBALANCE

## Description

This index characterises the magnitude and phase angle asymmetries of three-phase voltages in steady state operation. The voltage unbalance factor is defined using the theory of symmetrical components, as the ratio between the voltage negative sequence component and the positive sequence component.

## Causes

Voltage unbalances, which apply to three-phase voltages, have two main causes, i.e., asymmetries of line impedance and load unbalances.

## Method of evaluation

The voltage unbalance factor is evaluated using the R.M.S. value of the positive and negative sequence voltage components over two-hour time integration intervals under usual operating conditions. Periods during which the voltage of the three phases is lower than 50% of nominal voltage are excluded from this evaluation. The measurement method is described in reference [ 2 ].

## Indicative values

There is as yet no international recommendation concerning high voltage unbalance levels. As an indication, voltage unbalance factors under usual operating conditions 95% of the time over a one-week measurement period are generally lower than\*:

- 1% for voltage levels of 230kV and 315kV,
- 1.5% for voltage levels of 69 kV, 120 kV and 161 kV,
- 2% for voltage levels of 44 kV and 49 kV.

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*Notes* \* These values do not cover voltage unbalances caused by uncontrollable events such as geomagnetic storms, etc.

Higher values may be recorded over a limited period of time (50% of voltage unbalance during a short-circuit, for example), but these short-duration high unbalance levels do not produce a significant heating effect on equipment.

# FLICKER

## Description

Flicker translates the visual discomfort caused by repetitive changes of brightness in lighting. At certain frequencies, the eye can perceive the effect of very small voltage fluctuations on lighting. Most equipment, however, is not disturbed by this phenomenon.

## Causes

Flicker derives from voltage repetitive variations caused by certain industrial loads such as welding machines, rolling mills, large motors with variable loads, arc furnaces, etc.

## Method of evaluation

The index used to evaluate long-term flicker severity is the Plt, evaluated over two-hour time integration intervals. Flicker is measured with a flickermeter according to standard IEC 61000-4-15:1997 [ 5 ] whose weighting factors must be corrected for incandescent lamps at 120 V. The measurement method is described in reference [ 2 ].

## Target value

Under usual operating conditions, the level of flicker caused by the supply voltage variations is generally lower than  $P_{lt}=0.6$  (index for long-term flicker level), 95% of the time over a one-week measurement period.

This target value is the high voltage planning level given as an indicative value in the report IEC 61000-3-7:1996 [ 6 ] for co-ordinating levels of disturbance emission between parts of the system. Note that a higher value may appear at some high voltage points if it does not cause the compatibility levels to be exceeded at lower voltage levels.

## **SHORT INTERRUPTIONS (*duration < 1 min*)**

### **Description**

Short interruptions correspond to a temporary loss of supply voltage on all phases lasting less than 1 minute.

### **Causes**

Most of the time, short interruptions are caused by the action of devices designed to protect the system from short-circuits. On high-voltage lines, it is current practice to automatically reclose line breakers to restore power supply as soon as possible on a line disturbed by a fugitive fault. So, instead of an interruption, customers supplied by the disturbed line have just a short interruption lasting from 0.5 to 1.5 seconds, in the absence of co-ordination constraints on protections.

It must be stressed that automatic reclosing is used to ensure better continuity of service, by making it possible to avoid interruptions from fugitive faults. On the other hand, if the fault is permanent, the number of voltage dips for customers supplied by other lines increases a little.

### **Method of evaluation**

In practice, voltage dips of more than 90% may be viewed as short interruptions, since less than 10% of effective voltage supplying equipment then remains. The measurement method is described in reference [2].

### **Indicative values**

The annual number of short interruptions is unpredictable and varies greatly from place to place. There may be just a few cases a year in some places, but dozens in others. Short interruptions generally last less than a few seconds.

## **VOLTAGE DIPS**

### **Description**

Voltage dips are sudden reductions of more than 10% of nominal voltage, lasting between 8 milliseconds and a minute.

### **Causes**

Voltage dips are generally caused by a large current inrush generated by short-circuits on the system or on customer installations. They are unpredictable, largely random events. The annual frequency varies greatly with the type of supply system and point of observation, and their distribution over the year can be very irregular.

### **Method of evaluation**

The magnitude of voltage dips is measured by the percentage of voltage reduction, and their duration by the time during which the R.M.S. voltage of one of the phases — evaluated over every consecutive cycle of the 60 Hz waveform — falls below the threshold of 90% of nominal voltage. Measurement is continued until the voltage returns above this threshold. For a single event, the magnitude of voltage dips measured between phase-to-neutral differs from the phase-to-phase value. Values measured between phase-to-phase are generally more representative of the effect of voltage dips on industrial loads. The measurement method is described in reference [ 2 ].

### **Indicative values**

The annual number of voltage dips is unpredictable and varies greatly from one place to another. There may be just a few cases a year in some places, but dozens in others. Voltage dips generally last less than 500 milliseconds with a magnitude of less than 60%.

## TEMPORARY OVERVOLTAGES

### Description

Temporary overvoltages are sudden rises of the voltage R.M.S. value of more than 110% of nominal voltage. Temporary overvoltages may last between 8 milliseconds and one minute.

### Causes

Temporary overvoltages may be caused by short-circuits, load rejections or resonance and ferro-resonance phenomena. Generally, they result from overvoltages induced on healthy phases, during phase-to-ground faults for instance.

### Method of evaluation

We have a temporary overvoltage when voltage magnitude and the time during which the R.M.S. voltage of one of the phases —assessed over every consecutive cycle of 60 Hz — exceeds the 110% nominal voltage threshold. Measurement is continued till voltage of the three phases falls below this threshold once again. The measurement method is described in reference [2].

### Indicative values

The importance of overvoltages which are caused by single phase-to-ground short-circuits varies with fault location, system impedance and the effectiveness of neutral grounding, as follows:

- in the case of systems whose neutral is effectively grounded, phase-to-ground overvoltages on healthy phases are generally lower than 140% and typically last a few cycles to a few seconds, depending on the speed with which protection devices eliminate the fault;
- in the case of systems whose neutral is isolated or ungrounded, phase-to-ground overvoltages on the phases can reach 180 %\*, and systems of this type are designed according to such constraints.

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\* Note: Higher overvoltages can be generated by an arcing ground fault when the neutral is grounded through a capacitance, but such situation would be abnormal.

## FREQUENCY VARIATIONS

### Description

The nominal frequency of the alternating voltage supplied by the Hydro-Québec system is 60 Hz. This value is determined by the speed of the alternators at generating stations.

### Causes of variations

Maintaining system frequency depends on the balance between the load and the power produced by the generating stations. As this balance changes over time, we see small frequency variations whose magnitude and duration depend on load characteristics and on the response of generators. Additionally, the system may be subjected to greater variations from short-circuits, or load or generation changes causing temporary frequency variations whose magnitude and duration depend on the severity of the disturbance \*.

### Method of evaluation

Evaluated using the mean value of the system fundamental frequency, assessed over samples of 12 consecutive cycles. The measurement method is described in reference [ 2 ].

### Target value

The following value is based on standard CENELEC-EN50160 [ 1 ]. Under normal operating conditions, the main system frequency is maintained in a range less than plus or minus 1% or 0.6 Hz (that is to say between 59.4 Hz and 60.6 Hz), for at least 99% of time over a one-week measurement period.

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Note: \* Appendix B provides maximum frequency variation statistics monitored during disturbances occurring on the Hydro-Québec main transmission system between January 1991 and December 1998. As we see, frequency variations under normal operating conditions fall well within target values.

Remark: Higher frequency variations, for instance, plus or minus 4 Hz around the 60 Hz fundamental frequency (56 Hz with 64 Hz), can occur temporarily on parts of the system islanded following major disturbances or outages.

## **RAPID VOLTAGE CHANGES**

### **Description**

Rapid voltage changes are sudden but relatively weak voltage variations over the range of values defined for steady state voltage.

Occasional rapid voltage changes do not necessarily have much effect on flicker, but they can disturb some equipment, so their amplitude must therefore be limited.

### **Causes**

Most of the time, they result from load changes on customer installations or from switching operations on the supply system. They can be occasional or repetitive.

### **Method of evaluation**

Establishing the maximum difference of the R.M.S. voltage between two intervals, selected from three 3-second consecutive intervals. The R.M.S. voltage is evaluated over three-second time integration intervals. The measurement method is described in reference [ 2 ].

### **Target values**

The following values are based on the usual design criteria for reactive power compensation equipment or motor starting criteria, for example. Under usual operating conditions—excluding events such as short-circuits, interruptions—the magnitude of occasional rapid voltage changes (once per hour or less) should generally not exceed 3% of nominal voltage. In some circumstances\*, it can reach 6% of nominal voltage. For voltage variations repeating more than once an hour, amplitude is limited by the flicker index which is a function of the repetition rate.

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\*Note: These are viewed as degraded operating conditions when equipment switching must be carried out to meet supply system or load requirements.

## TRANSIENT OVERVOLTAGES

### Description

These are disturbances of very short duration, lasting typically less than one half-cycle, i.e. a few microseconds ( $\mu\text{s}$ ) to several milliseconds (ms). Transient overvoltages can be impulses or oscillations and they can damage equipment insulation or electronic components.

### Causes

Overvoltages may be caused by:

- switching of system lines and equipment, in particular, the switching-in of capacitor banks resulting in a damped oscillation that superimposes onto the fundamental wave, whose oscillation frequency generally lies between 100 Hz and 9 kHz, with a peak duration less than  $\frac{1}{2}$  cycle;
- lightning, generally resulting in the appearance of an impulse; having, in the fastest cases, a rise time of about one microsecond.

### Method of evaluation

Measuring the voltage waveform and its instantaneous crest value with a device of sufficiently large bandwidth compared to the frequency of the phenomena considered.

### Indicative values

A lot of attention is paid to transient overvoltages when it comes to coordinating the insulation of equipment connected to high voltage systems, and they are covered by various standards, including standards CSA CAN3-C308 [ 7 ] and those of the IEC series 71 [ 8 ].

In the case of the switching-in of shunt capacitor banks, a frequent operation on the high voltage system, the magnitude of transient overvoltages is typically lower than twice the system crest line-to-ground voltage. This value can be higher in the case of wave reflections or resonance between customer equipment and the supply system.

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\* Note: Appendix C provides statistics on transient overvoltages recorded in 21 stations at the high voltage system between 1993 and 1995.

## References:

This document is based on the work of the inter-division internal working group on supply voltage characteristics and on the following references:

- [ 1 ] Voltage characteristics of electricity supplied by public distribution systems, Standard CENELEC EN50160:1994.
- [ 2 ] Measurements methods of the characteristics and target values of the voltage quality supplied by Hydro-Québec system. IREQ Report 99-220, rev. 1 dec. 2000.
- [ 3 ] Preferred voltage levels for AC systems 0 to 50000V, Standard CSA CAN3-C235-83.
- [ 4 ] Assessment of emission limits for distorting loads in MV and HV, Report – type 3, CEI 61000-3-6. Oct. 1996.
- [ 5 ] Testing and measurement techniques –Section 15: Flickermeter – Functional design specifications. IEC 61000-4-15:1997 Standard
- [ 6 ] Assessment of emission limits for fluctuating loads in MV and HV, Report - type 3, IEC 61000-3-7. Oct.1996.
- [ 7 ] The Principle and Practice of Insulation Coordination - Electric Power Systems and Equipment. CSA CAN3-C308-M85 Standard.
- [ 8 ] Insulation Coordination, Parts I and 2. Standards IEC 71-1 and 71-2.

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Note: Some works are cited for reference purposes only and are therefore not necessarily applicable to Hydro-Québec.

## APPENDIX A (informative) SERVICE CONTINUITY INDEX STATISTICS

### Description

The continuity index is a measurement of the average duration of interruption per customer supplied by the transmission system. This index is derived considering outage durations, programmed interruptions and short interruptions (< 1 min.).

The continuity index (CI) is expressed in hours and it is derived as follows:

$$CI = \frac{\text{Sum of Customer-Hours interrupted}}{\text{Sum of all customers}}$$

The index to be compared with the target values is the adjusted index corrected by excluding exceptional events and "*force majeure*" (e.g., the January 1998 ice storm).

### History and target

The following table gives the historical values of the adjusted CI and the target set for the coming years:

| Year                   | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999-2002       |
|------------------------|------|------|------|------|------|------|------|-----------------|
| Adjusted CI index (hr) | 0.71 | 1.15 | 0.58 | 0.62 | 0.44 | 0.61 | 0.48 | Target:<br>0.65 |

The transmission system service continuity index is the subject of annual objectives published in the TransÉnergie business plan.

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## APPENDIX B (informative) STATISTICS ON FREQUENCY VARIATIONS

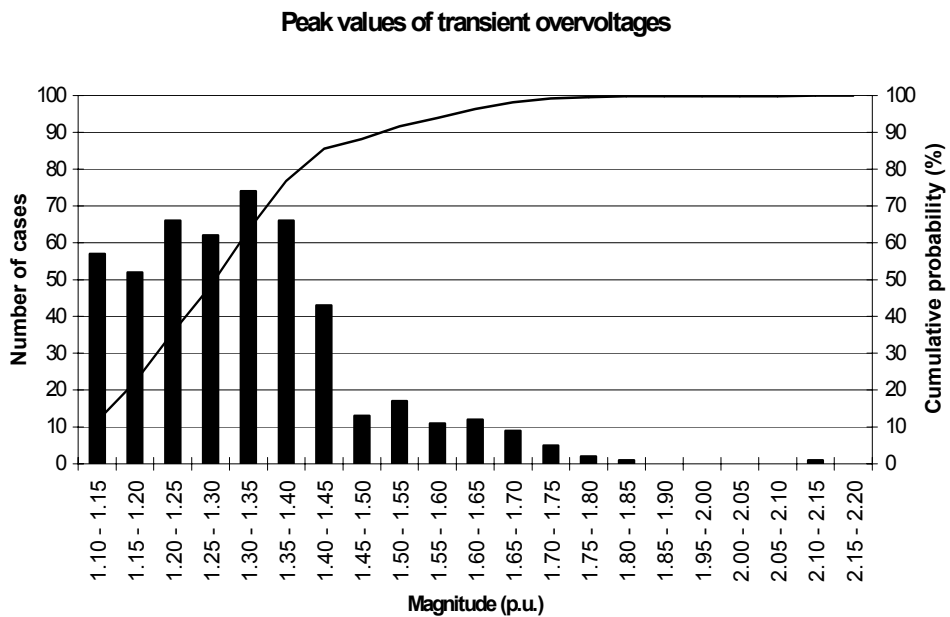
The following statistics are based on measurement of the maximum values of frequency variations recorded during disturbances on the Hydro-Québec main system between January 1991 and December 1998. The average occurrence is derived on an annual basis from statistics on events occurring in that period.

| FREQUENCY VARIATIONS ( $\Delta f$ )   | SYSTEM CONDITION                              | AVERAGE OCCURRENCE    | TYPICAL DURATION   |
|---|---|-----------------------|--|
| + 0.5 Hz to + 1 Hz  | Rare disturbed conditions                     | Once a year           | -  |
| + 0.20 Hz to + 0.5 Hz   | Frequent disturbed conditions                 | 24 times a year       | Typically less than 10 s, but can occasionally last several minutes. |
| <b><math>\pm 0.20</math> Hz</b>   | <b>Normal conditions without disturbances</b> |                       | <b>Steady State</b>  |
| - 0.20 Hz to - 0.5 Hz   | Frequent disturbed conditions                 | 49 times a year       | Typically less than 10 s, but can occasionally last several minutes. |
| - 0.5 Hz to - 1 Hz  | Frequent disturbed conditions                 | 20 times a year       |  |
| - 1 Hz to - 1.5 Hz  | Rare disturbed conditions                     | Less than once a year | -  |
| Remark : Higher frequency variations, for instance, plus or minus 4 Hz around the fundamental frequency of 60 Hz (56 Hz with 64 Hz), can occur temporarily on parts of the system islanded following major disturbances or outages. |   |                       |  |

## APPENDIX C (informative) STATISTICS ON TRANSIENT OVERVOLTAGES

The following data are based on values obtained at 21 stations of the high voltage system during a measurement series between 1993 and 1995. The values indicated on the graph were measured between phase-to-neutral. The graph presents the cumulative number of transient overvoltages recorded at all 21 stations.

### Distribution of the number of transient overvoltages versus magnitude



## APPENDIX D

### EXTRACTS FROM BYLAW NUMBER 634 RESPECTING THE CONDITIONS GOVERNING THE SUPPLY OF ELECTRICITY

Act respecting Hydro-Québec, (R.S.Q., c.H-5, s.22.01)

Reference to some provisions of Bylaw 634 on the conditions governing the supply of electricity does not render inapplicable the whole of the provisions of the aforesaid Bylaw.

64. *The customer's electrical installation must correspond to information supplied by the customer to Hydro-Québec pursuant to Section 76 and must allow connection at the voltage supplied by Hydro-Québec.  
The installation must be approved or authorized by an authority having jurisdiction in this realm pursuant to any applicable legislative or regulatory provision and must be built, connected, protected, utilized and kept up in such a way that it does not disturb the system, jeopardize the quality of the supply of electricity to the installations of the other customers or put Hydro-Québec's representative at risk.*
66. *The customer must ensure the protection of property and the safety of persons wherever electricity is supplied or delivered and he is responsible for protecting himself from the consequences of any interruption in the supply or delivery of electricity and for protecting his electrical installation and apparatus from voltage variations and losses, frequency variations and accidental groundings.*
67. *The type, characteristics and adjustment of the customer's protective equipment must allow for coordination of the customer's protection with that of Hydro-Québec.*
68. *When electricity is supplied at medium or high voltage by several power lines, the customer must use it through the lines Hydro-Québec indicates to him.  
Where one of designated lines fails or requires an outage, the customer must, with Hydro-Québec's authorization or at its request, use the electricity through another line indicated by Hydro-Québec, solely for the duration of work, unless Hydro-Québec indicates a longer period of use to him.*
69. *The customer may not use electrical generating equipment in parallel to Hydro-Québec's system, unless he obtains Hydro-Québec's written authorization to do so.*
70. *When the customer installs an emergency generator set, the latter must be equipped with a manual or automatic switching device authorized by Hydro-Québec.*
71. *The customer must immediately inform Hydro-Québec of any electrical or mechanical defect in his electric installation likely to disturb Hydro-Québec's system, jeopardize the supply of electricity to other customers or put property or persons at risk.*
72. *When electricity is supplied at medium or high voltage, Hydro-Québec, in order to manage its system, must be able to communicate at all times with authorized persons pursuant to the Master Electricians Act (R.S.Q., chapter M-3), designated by the customer.  
The customer must immediately inform Hydro-Québec of the replacement of the aforesaid persons*

74. *The customer must use electricity according to the available power limit in such a way that he does not disturb Hydro-Québec's system, hinder the supply of electricity to other customers or put Hydro-Québec's representative at risk*
76. *The customer provides Hydro-Québec with information respecting the use to which electricity is put and the characteristics of his electrical installations, as required for the management or safety of the system. He then must notify Hydro-Québec immediately of any change in the information supplied.*
94. *Hydro-Québec delivers and supplies electricity subject to interruptions which may arise from an emergency, an accident, equipment failure or the activating of protective equipment within the system.*
95. *Hydro-Québec may, at any time, interrupt the supply or delivery of electricity for the purpose of upkeep, repairs, modification or management of the system, or for reasons of public utility or safety.*
102. *Hydro-Québec guarantees neither the maintenance of voltage and frequency at a stable level nor the continuity of the supply and delivery of electricity. In no case shall it be held contractually or extra-contractually liable for damage caused to property resulting from the supply or delivery of electricity or failure to supply or deliver electricity, or resulting from accidental grounding, mechanical failure on its system, any interruption of service covered by Division V of chapter VI, frequency variations or supply voltage variations.*

*Hydro-Québec shall not be held liable for damage resulting from a steady state supply voltage not exceeding the following limits:*

- (1) if the electricity is supplied at low or medium voltage: according to the standard mentioned in Section 18;*
- (2) if the electricity is supplied at high voltage: a difference of up to 10% above or below the nominal supply voltage.*

*Hydro-Québec shall not be held liable for damage resulting from events of force majeure, even when such events or force majeure cause supply voltage variations exceeding the limits mentioned in the second paragraph.*

104. *Any contract and any agreement concluded under this Bylaw, any installation effected by Hydro-Québec and any connection between the system and the customer's electrical installation, any authorization given by Hydro-Québec, any inspection or verification effected by it, and the supply and delivery of electricity by it do not constitute and must be interpreted as constituting an evaluation or a guarantee by Hydro-Québec of the functional value, efficiency or safety of the customer's installations, including his electrical installation and protective devices, nor of their compliance with any applicable legislative or regulatory provision.*

*When the customer does not use electricity according to Section 74, he is liable for any damage caused to other customers or to Hydro-Québec.*