Emission Limits for Customer Facilities Connected to the Hydro-Québec Transmission System

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

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1 General

1.1 PURPOSE

This document sets out the emission limits and assessment methods for electrical disturbances caused by equipment in customer facilities connected to, or to be connected to, the Hydro-Québec transmission system. These limits apply to harmonic emissions, load or current imbalances, rapid voltage changes and flicker at the interface between a customer facility and the transmission system. They are intended to ensure that disturbance levels in the transmission system caused by all facilities remain within power quality targets set out in reference [1]. Even if these emission limits are achieved on the transmission system side, disturbance levels within the customer facility under consideration may still be too high for some of his equipment to work properly. Further reduction of emissions may then be needed on the customer facility side to meet his specific equipment requirements.

This document covers the most common disturbances. Some equipment may produce other types of disturbances, e.g., interharmonics, subharmonics, harmonics above 3 kHz or repetitive bursts of harmonic currents. Depending on the magnitude of such disturbances and their potential impact on the transmission system or third-party facilities, further emission limits may be specified during planning, pre-connection or upgrade studies for a customer facility.

1.2 SCOPE

Emission limits and assessment methods set out in this document are for customer facilities (loads or generation) connected to, or to be connected to, the Hydro-Québec transmission system at voltages of 44 to 345 kV. More specifically, they apply to projects that:

- Connect new customer facilities to the power system or recommissioned facilities the customer has decommissioned or shut down
- Add disturbance-producing equipment
- Change equipment characteristics at existing facilities, or how equipment is operated or functions, in a way that may increase emission levels for disturbances (in magnitude or repetition rate) beyond allowable limits

Emission limits for an existing customer facility whose emission-related characteristics have not been changed since connection to the power system are those initially specified when the facility was designed. However, if the emission limits and assessment methods in this document are less stringent, the customer may elect to apply them.

The emission limits set out in this document do not apply to customer facilities connected to Hydro-Québec distribution systems.

1.3 DEFINITIONS

In this document, the definitions below apply.

95% (or 99%) daily value

A 95% daily value means that there is a 95% statistical probability that the disturbance level will not exceed that value during any given day. Similarly, a 99% daily value means that there is a 99% statistical probability that the disturbance level will not exceed that value during any given day. The 95% and 99% daily values thus correspond to the daily peaks when ignoring the top 5% or 1% of daily values respectively. Its assessment must be over a long enough period to reflect all possible operating conditions.

Characteristic and non-characteristic harmonics

Characteristic harmonics are the theoretical values of harmonics produced by various types of equipment under ideal operating conditions. In practice, some degree of dissymmetry inevitably exists on the power system and at customer facilities, in addition to other non-ideal operating conditions, which may cause "non-characteristic" harmonics to be generated (see Section 3.6.2). Non-characteristic harmonics may cause emission levels to rise appreciably, especially if they are amplified by parallel resonance from filters or if they interact unfavourably with converter control systems.

Current imbalance

The condition that arises when individual currents of a three-phase system are not of equal magnitude or are not phase-shifted 120° from one another.

Customer facility

All of a customer's support structures, other structures, switchgear, and equipment consuming or generating electricity, that are located on the customer side of the *connection point.* Here, they comprise the electrical installations that are or will be connected to the Hydro-Québec transmission system.

Cycle

The duration of the power system's fundamental AC-voltage waveform. For a frequency of 60 Hz, the duration is 1/60th of a second or 16,67 milliseconds[1]..

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[1] Following IEC and other international standards, the decimal sign used throughout this document is the comma (,) rather than the point (.).

Disturbance-producing equipment

Equipment, apparatus, systems, devices or processes that can generate or amplify harmonics, imbalances, rapid voltage changes, flicker or any combination of these disturbances.

Emission limits

In this document, the maximum emission levels allowed from harmonics, imbalances, flicker or rapid voltage changes that may be generated or amplified by all disturbance-producing equipment in a customer facility.

Emission levels

The contribution from a customer facility to the level of disturbances that may be transmitted over the power system by all disturbance-producing equipment in the facility under study. Emission levels are evaluated using the methods specified in this document, particularly in Section 3.

Flicker

The impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates over time. Flicker is the effect on lighting of repetitive voltage variations at frequencies to which the human eye is particularly sensitive, especially from 0,1 to 25 Hz.

Fluctuating loads

Broadly, equipment or facilities that utilize or produce power whose fluctuations or demand at start-up or during switching operations can cause flicker or rapid voltage changes (e.g., arc and induction furnaces, welding machines, presses, winches, rolling mills and other intermittently operated motors, motor start-ups, capacitor bank switching, and power fluctuations from generators or wind turbines).

General operating conditions

All operating conditions that collectively have a statistical probability of occurring more than 5% of the time over one year. They include daily or seasonal variations in electrical load and generation, and the switching operations they entail, as well as frequent or prolonged equipment outages or down time either on the power system or at customer facilities.

Note: The present and foreseeable future of systems must be considered in assessing general operating conditions.

Grid harmonic impedance loci

The parameters defining the range of possible transmission system impedances for harmonic orders subject to emission limits. Grid harmonic impedance loci do not include the effect of the customer facility under study. Impedance loci are generally defined in the plane R ± jX and delimited as circles, sectors or polygons.

Harmonics

Sinusoidal voltages or currents having frequencies that are integral multiples of the fundamental frequency of the power system (60 Hz). A distorted wave can be decomposed into component sine waves at the fundamental frequency and multiples of that frequency, i.e., its harmonics. Besides distortion and other unwanted changes to the waveform, harmonics can cause interference on nearby voice-frequency analog communication lines.

High voltage (HV)

In this document, any part of the transmission system whose nominal voltage is between 44 kV and 345 kV.

Interharmonics

Voltages or currents having frequencies that are non-integral multiples of the fundamental frequency of the power system (60 Hz).

Load imbalance

The design or operating characteristic of facilities for which the imbalance in current consumed or power generated may cause voltage imbalance on the power system (see also Unbalanced facilities).

Nominal voltage of a system (voltage level)

The phase-to-phase RMS voltage used in designating a power system. The nominal voltages (V_{nom}) of the transmission system are generally as follows: 44 kV, 49 kV, 69 kV, 120 kV, 161 kV, 230 kV, 315 kV and 345 kV.

Occasional operating conditions

All operating conditions that are likely to produce emission levels higher than those under general operating conditions, and do so up to 5% of the time over one year. They generally correspond to abnormal operation conditions due to short or infrequent equipment outages or down time either on the power system or at customer facilities.

Note: The present and foreseeable future of systems must be considered in assessing occasional operating conditions. Emission limits are not intended to cover exceptional extreme conditions.

Point of evaluation

The point located on the high-voltage transmission system side where emission levels from a given customer facility must be evaluated for comparison with allowable emission limits. If other customer facilities may be connected near the facility under study, the point of evaluation will generally be the connection point, or the high-voltage side of transformers if the connection point is on the low-voltage side of the transformers. The Transmission Provider may specify another point of evaluation depending on the specific power system characteristics and on other customer facilities potentially connected nearby.

Rapid voltage changes

Sudden random or cyclical variations in the RMS voltage between successive levels, which can be attributed to fluctuating loads in the customer facility. A voltage change is considered to be rapid when the variation between two successive levels occurs in one minute or less.

Reference power (S_r)

The anticipated power in MVA of a customer facility used to determine the emission limits applying to that facility. It also provides a basis for specifying emission levels with respect to limits (see sections 3.1 and 3.4).

Short-circuit power (S_{sc})

The theoretical MVA short-circuit power of the transmission system corresponding to the short-circuit power for a three-phase fault at the point of evaluation for a customer facility. For the purpose of applying the emission limits herein, Hydro-Québec provides this value for general operating conditions and, if required, for occasional operating conditions.

Note: In practice, the short-circuit level is often defined by means of the symmetrical short-circuit current (I_{sc}). The three-phase short-circuit power (S_{sc}) can be calculated as the product of the three-phase short-circuit current (I_{sc}) and the nominal voltage (V_{nom}) at the point of evaluation times √3 (i.e., $S_{sc} = \sqrt{3} \bullet I_{sc} \bullet V_{nom}$).

Unbalanced facilities

Broadly, equipment or facilities consuming or producing power whose current imbalance may cause voltage imbalance on the power system (e.g., arc and induction furnaces, single- or two-phase loads and generators, and electric train AC power supplies).

Voltage imbalance

The condition that arises when individual voltages of a three-phase system are not of equal magnitude or are not phase-shifted 120° from one another.

2 Emission Limits

2.1 HARMONICS

Emission limits below apply to harmonics caused by all disturbance-producing equipment in a customer facility.

2.1.1 Simplified assessment

Customers with facilities referred to in Section 1.2 need not produce a detailed assessment of harmonic emissions propagated to the transmission system if the total power of its facility's harmonic-producing equipment does not exceed that in Table 1 and is less than 0,25% of the short-circuit power (S_{sc}) at the point of evaluation under general operating conditions. The customer must, however, confirm in writing to Hydro-Québec the total power of its harmonic-producing equipment to demonstrate that its facility meets criteria for simplified assessment.

Table 1

Voltage level (kV)	Total three-phase power* of harmonic-producing equipment (MVA)
44, 49	1
69	1,5
120	2,7
161	3,6
230	5
315, 345	7

* Note: Provided this does not exceed 0,25% of short-circuit power under general operating conditions.

2.1.2 Detailed assessment

If a facility referred to in Section 1.2 has disturbance-producing equipment (e.g., arc or induction furnaces, rectifiers for electrolysis, motor drives, frequency converters, AC load controllers) that exceeds the criteria set out in Section 2.1.1, the customer must provide Hydro-Québec with a detailed study of harmonic emissions caused by its facility using the method described in Section 3. The customer must thus demonstrate that the facility is designed to comply with the limits given in sections 2.1.2.1 and 2.1.2.2.

2.1.2.1 Emission limits for harmonic currents

General operating conditions: Tables 2, 3 and 4 give harmonic emission limits to be met at the point of evaluation under general operating conditions. These limits apply to harmonic orders n = 2 to 50 inclusively and are ratios of harmonic current (I_n/I_r) expressed in percent of the line current (I_r) corresponding to the reference power of the customer facility. The limits are based on the ratio of system short-circuit power (S_{sc}) under general operating conditions to customer facility reference power (S_r). It is acceptable to use segmented linear interpolation between consecutive S_{sc}/S_r values in the table below and to estimate proportionally for values above 200 (see Note 2 – next page). If S_{sc}/S_r is lower than 5, Hydro-Québec must first conduct analyses to determine the specific emission limits and technical conditions applicable. Reference [4] may be used for guidance in such analyses. Note that the telephone influence factors specified in Section 2.1.2.2 may set a tighter constraint for current allowable at certain harmonic orders.

Table 2 – Emission limits for currents at odd harmonics (I_n/I_r %)

S_{sc}/S_r	n=3	n=5	n=7	n=9	n=11, 13	15≤n<23	23 ≤ n <35	n≥ 35
5	1	1,2	0,8	0,5	0,5	0,4	0,3	0,2
20	1,5	2	1,5	0,75	1	0,65	0,45	0,3
50	2	3	2	1	1,5	1	0,7	0,5
200	3	4	3	1,25	2	1,5	1	0,7

Table 3 – Emission limits for currents at even harmonics (I_n/I_r %)

S_{sc}/S_r	n=2	n=4	n=6	n=8	n ≥ 10
5	0,75	0,5	0,3	0,2	0,15
20	1,1	0,75	0,45	0,3	0,25
50	1,5	1	0,6	0,4	0,3
200	2,2	1,5	1	0,6	0,4

Table 4 – Emission limits for total harmonic current distortion for orders up to n = 50

S_{sc}/S_r	TDD_c
5	1,7
20	3
50	4,5
200	6

NOTES:

1) Definition of indices or symbols in Tables 2, 3 and 4 above:

Ratio of individual harmonic currents $\frac{I_n}{I_r} \cdot 100\%$ (*n*: harmonic order) (Eq. 1)

Total current distortion $TDDc = \frac{1}{I_r}\sqrt{\sum_{n=2}^{50} I_n^2} \cdot 100\%$ (Eq. 2)

where:

I_n Emission level for order n = 2 to 50 harmonic currents (highest phase RMS currents) at the point of evaluation (A_{rms}) (see Section 3.6)

I_r The root-mean-square line current for customer facility reference power (S_r) at the nominal voltage of the high-voltage system at the point of evaluation (A_{rms}) (see Section 3.4)

2) For facilities where ratio S_{sc}/S_r at the point of evaluation lies between two consecutive values in tables 2, 3 or 4, segmented linear interpolation is allowed using Equation 3 to determine the emission limits applicable to the facility under study.

$$\left(\frac{I_n}{I_r}\right)_i = \left[\frac{\left(I_n/I_r\right)_B - \left(I_n/I_r\right)_A}{\left(S_{SC}/S_r\right)_B - \left(S_{SC}/S_r\right)_A}\right] \bullet \left[\left(\frac{S_{sc}}{S_r}\right)_i - \left(\frac{S_{sc}}{S_r}\right)_A\right] + \left(I_n/I_r\right)_A \quad \text{(Eq. 3)}$$

Where: ***i*** = the facility under study

A = row of table 2, 3 or 4 where S_{sc}/S_r is just lower than that of the facility under study

B = row of table 2, 3 or 4 where S_{sc}/S_r is just higher than that of the facility under study

If S_{sc}/S_r is greater than 200, projection of limits for harmonic currents is allowed proportionately to ratio S_{sc}/S_r for the facility under study, as given in Equation 4:

$$\left(\frac{I_n}{I_r}\right)_i = \left[\left(\frac{S_{sc}}{S_r}\right)_i \div 200\right] \bullet \left(I_n/I_r\right)_{200} \quad \text{(Eq. 4)}$$

Equations 3 and 4 also apply to TDD_c, replacing (I_n/I_r) with TDD_c in them.

3) Limits apply to harmonic emission levels assessed over 10-minute aggregation intervals (see note following) in accordance with IEC 61000-4-7 [2] and with Class A requirements of IEC 61000-4-30 [3]. Emission levels must have a 95% daily value below allowable emission limits. Emission levels must have a 99% daily value not exceeding 1,5 times the allowable emission limits (see 3.6).

4) Repetitive bursts of high harmonic currents subject to specific limits (see Section 1.1) should be assessed based on shorter aggregation intervals, e.g., 3 seconds instead of 10 minutes.

Occasional operating conditions: Customers for whom the ratio of system short-circuit power under general operating conditions to facility reference power (S_{sc}/S_r) is less than 30 must submit an assessment of emission levels under occasional operating conditions to ensure that they do not exceed 1,5 times the allowable limits under general operating conditions.

2.1.2.2 Telephone influence limits

When harmonics emitted by a customer facility propagate down transmission lines they may cause interference on nearby voice-frequency analog telephone lines. Besides the limits above to control voltage waveform distortion effects, emissions must also be limited to minimize risks of telephone interference by induction between the power system and communication network.

A detailed assessment of the telephone influence factor is not required for facilities meeting the criteria for simplified assessment under Section 2.1.1. In other instances, the limits below apply.

General operating conditions: Table 5 gives the telephone influence limits applicable under general operating conditions. It gives two limits: a general limit and a higher specific limit that can be applied if the customer provides a detailed study demonstrating that at least one of the criteria in Table 5 is met (see also Section 3.6.4). These criteria are based on the equivalent length over which the two lines run parallel, equivalent soil resistivity at 1000 Hz, and minimum separation and mutual impedance at 1000 Hz between the telephone line and power line, which may produce interference due to harmonic currents emitted by the customer facility under study. If there is no existing or planned voice-frequency analog telephone line within 10 km of the transmission lines affected, the following limits need not be applied.

Table 1 – Telephone influence limits
(analog voice-frequency telephone network)

<table>
<tr><th colspan="4">Criteria for application</th><th>I·T_{balanced} limit (A_{weighted})</th></tr>
<tr><td colspan="4">General limit</td><td>15000</td></tr>
<tr><td colspan="4">Specific limit if at least one of the criteria below is met
(see note below)</td><td rowspan="2">30000</td></tr>
<tr><td>$\mathbf{L_{eq}} \leq 1$ km</td><td>Or
$\rho_{eq} \leq 300$ Ω•m</td><td>Or
$\mathbf{S_{min}} \geq 5$ km</td><td>Or
$\mathbf{Z_m} \leq 2$ Ω</td></tr>
</table>

Note: The Transmission Provider will determine the transmission lines *affected*, i.e., those to be analyzed by the customer to demonstrate that the specific limit in Table 5 is applicable. The lines to be analyzed may include lines or line sections that are electrically linked to the line(s) serving the customer facility and over which more than 50% of the high-frequency harmonic currents emitted by the facility under study may flow.

Where: (see also Section 3.6.4)

L_{eq} Total equivalent length over which individual telephone lines run parallel to power lines affected by harmonics emitted by a customer facility (km)

ρ_{eq} Equivalent soil resistivity at 1000 Hz along the power lines affected (Ω•m)

S_{min} Minimum equivalent distance separating the power lines affected and telephone lines (km)

Z_m Mutual impedance in ground mode at 1000 Hz between the individual telephone lines and the power lines affected (Ω)

NOTES:

5) The telephone influence factor I•T $_{balanced}$ in Table 5 is given by:

$$I \cdot T_{balanced} = \sqrt{\sum_{n=2}^{50} \left(I_n \cdot W_n \right)^2} \quad \text{(A-weighted)} \qquad \text{(Eq. 5)}$$

Where:

W_n Weighting factor for telephone influence given in Table 6

I_n Emission level for order n = 2 to 50 harmonic currents (highest phase RMS currents) at the point of evaluation for the customer facility on the transmission system (A_{rms})

6) Harmonic current values to use in calculating the telephone influence factor are based on the principles set out in the preceding section and the methods described in Section 3.6 (particularly in sections 3.6.1 and 3.6.4).

Table 2 – Weighting factors W_n for the telephone influence factor I·T

n	F (Hz)	W_n	n	F (Hz)	W_n
-	-	-	26	1560	6790
2	120	10	27	1620	6970
3	180	30	28	1680	7060
4	240	105	29	1740	7320
5	300	225	30	1800	7570
6	360	400	31	1860	7820
7	420	650	32	1920	8070
8	480	950	33	1980	8330
9	540	1320	34	2040	8580
10	600	1790	35	2100	8830
11	660	2260	36	2160	9080
12	720	2760	37	2220	9330
13	780	3360	38	2280	9590
14	840	3830	39	2340	9840
15	900	4350	40	2400	10090
16	960	4690	41	2460	10340
17	1020	5100	42	2520	10480
18	1080	5400	43	2580	10600
19	1140	5630	44	2640	10610
20	1200	5860	45	2700	10480
21	1260	6050	46	2760	10350
22	1320	6230	47	2820	10210
23	1380	6370	48	2880	9960
24	1440	6650	49	2940	9820
25	1500	6680	50	3000	9670

Occasional operating conditions: Customers for whom the ratio of system short-circuit power under general operating conditions to facility reference power (S_{sc}/S_r) is less than 30 must also submit an assessment of emission levels under occasional operating conditions to ensure that they do not exceed 1,5 times the allowable limits under general operating conditions.

2.2 LOAD (OR CURRENT) IMBALANCE

The limits below apply to customer facility load or current imbalances that may cause voltage imbalance on the transmission system. The imbalance here involves the negative-sequence component of currents or voltages calculated using the symmetrical component method.

2.2.1 Simplified assessment

A customers with a facility referred to in Section 1.2 need not produce a detailed assessment of emissions from unbalanced loads propagated to the transmission system if the imbalance from its facility is equivalent to a 0,2% or lower single-phase load with respect to the system three-phase short-circuit power under general operating conditions. An alternative calculation to verify this criterion consists in finding the ratio (I_{neg}/I_{sc} in %) between the facility negative-sequence current (I_{neg}) and the system short-circuit current (I_{sc}) at the point of evaluation. The customer must confirm in writing to Hydro-Québec the value of the single-phase power equivalent to its facility's load imbalance to demonstrate that it meets criteria for simplified assessment (see also Section 3.7).

2.2.2 Detailed assessment

If a facility referred to in Section 1.2 has unbalanced loads (e.g., arc or induction furnaces, single- or two-phase loads, distributed electric train power supplies) that exceed the limits set out in Section 2.2.1, the customer must provide Hydro-Québec with a detailed study of emissions caused by unbalanced loads in its facility using the method described in Section 3. The customer must thus demonstrate that its facility is designed to comply with the limits below.

2.2.2.1 Emission limits for load (or current) imbalance

General operating conditions: Table 7 gives the emission limits for load or current imbalance to be met under general operating conditions. It is the current imbalance factor (I_{neg}/I_r) defined as the ratio of the negative-sequence component of load current (I_{neg}) to the current (I_r) corresponding to the reference power (see sections 3.4 and 3.7.1). The limits also depend on the ratio of system short-circuit power (S_{sc}) to customer facility reference power (S_r). Linear interpolation between Table 7 S_{sc}/S_r values and projection of limits for values above 200 are allowed in a similar way as described in Section 2.1.2.1, replacing (I_n/I_r) by (I_{neg}/I_r) in Equation 3. If S_{sc}/S_r is lower than 5, Hydro-Québec must first conduct analyses to determine the specific emission limits and technical conditions applicable. Reference [6] may be used for guidance in such analyses.

Hydro-Québec may determine on what phase(s) the customer must connect its unbalanced loads so as to minimize the resulting level of system voltage imbalance.

Table 3 – Emission limits for unbalanced loads (negative-sequence component percentage: I_{neg} / I_r as %).

S_{sc}/S_r	I_{neg} / I_r (%)
5	**4**
20	7
50	13
100	20
200	30

NOTES:

7) Definition of factors and symbols in Table 7:

Load current imbalance factor $\frac{I_{neg}}{I_r} \times 100\%$ (Eq. 6)

Where:

I_{neg} Root-mean-square value of the negative-sequence component of the current at 60 Hz due to customer facility load imbalance at the point of evaluation (A_{rms}) (see Section 3.7)

I_r The root-mean-square line current for customer facility reference power (S_r) at nominal voltage assessed at the point of evaluation on the high-voltage system (A_{rms}) (see Section 3.4)

8) The preceding limits apply to emission levels for load current imbalance (negative-sequence component ratio I_{neg} / I_r – see Eq. 6) assessed over 10-minute aggregation intervals, in accordance with Class A requirements of IEC 61000-4-30 [3] and with the guidelines in Section 3.7.2. Emission levels must have a 95% daily value below allowable emission limits. Emission levels must have a 99% daily value not exceeding 1,5 times the allowable emission limits (see Section 3.7).

Occasional operating conditions: Customers for whom the ratio of system short-circuit power under general operating conditions to facility reference power (S_{sc}/S_r) is less than 30 must also submit an assessment of emission levels under occasional operating conditions to ensure that they do not exceed 1,5 times the allowable limits under general operating conditions.

2.2.2.2 Emission limits for imbalances from electric train systems

Emission limits for load imbalance from single- or two-phase AC units powering electric trains are set after Hydro-Québec conducts a specific study to determine acceptable transmission system connection criteria based on system-specific conditions and on other sources of voltage imbalance that may exist on the system.

Under general operating conditions, the contribution to voltage imbalance (G_{Uneg}) due to all loads connected to a given system must not, however, exceed 0,4% of the negative-sequence voltage imbalance factor (V_{neg} / V_1) for systems at 230 kV or higher, and 0,7% (V_{neg} / V_1) for 44- to 161-kV systems (these values factor in other inherent transmission system asymmetries).

Only part of the global contribution above (G_{Uneg}) may be allocated as the emission limit for imbalance in powering an electric train drive system based on system characteristics and the characteristics of other loads using the equation below (the square root accounts for the fact that unbalanced loads of this type fluctuate and are generally not in phase with other unbalanced loads).

$$E_{Uneg} = G_{Uneg} \bullet \sqrt{\frac{S_r}{S_t}} \qquad \text{(Eq. 7)}$$

Where:

E_{Uneg}	Emission limit for imbalance (negative-sequence voltage) allowed for the electric train load under study
G_{Uneg}	Global contribution of the load imbalance (negative-sequence voltage) allowed in the system under study (0,4% or 0,7% depending on the voltage level)
S_r	Reference power of the load under study, assessed according to Section 3.4
S_t	Total power of potentially unbalanced loads that may be supplied from the high-voltage system under study (MVA) accounting for future loads

If applying Equation 7 results in a value of less than 0,2%, a minimum emission limit for imbalance E_{Uneg} = 0,2% will be allowed. Reference [6] gives additional information to consider, if needed.

Hydro-Québec may determine on what phase(s) the customer must connect its unbalanced loads so as to minimize the resulting level of system voltage imbalance.

Once emission limits have been determined, the emission study that the customer is to conduct will be based on the general principles in Section 2.2.2.1 and on the methods in Section 3, particularly Section 3.7.

2.3 RAPID VOLTAGE CHANGES

The following limits apply to rapid changes in RMS voltage that occur no more than 10 times per hour and are caused by all fluctuating loads in a customer facility. More frequent voltage changes are subject to emission limits for flicker dealt with in Section 2.4.

Since this type of disturbance is generally easy to assess, no simplified approach is required.

2.3.1 Detailed assessment

2.3.1.1 Emission limits for rapid voltage changes

General power system operating conditions : If a facility referred to in Section 1.2 has fluctuating loads, the customer must provide Hydro-Québec with a detailed study of emissions for rapid voltage changes caused by its facility using the method described in Section 3. The customer must thus demonstrate that its facility is designed to comply, at the point of evaluation under general operating conditions, with the voltage variation limits (ΔV/V) in Table 8 (see also Section 3.8.1). If a customer facility has fluctuating loads capable of producing rapid voltage changes simultaneously at different Table 8 repetition rates, the voltage variation limits at those rates must be divided by $\sqrt[3]{x}$, where x is the number of fluctuating loads involved.

Table 8 – Emission limits for rapid voltage changes

Repetition rate (variations/hour)	Voltage variation ΔV/V (%)
≤ 2	3
> 2 and ≤ 10	2,5

Note: A drop in voltage followed by a rise, or vice versa, counts as two voltage variations.

NOTES:

9) Non-repetitive transients shorter than 2 cycles are not covered by these limits.

10) Unlike other types of disturbances, rapid voltage changes are intermittent disturbances that must be assessed based on forecast maximum values rather than on statistical levels over time.

11) These limits are to be compared to the difference between minimum and maximum RMS voltage values over successive 3-second periods. The values of the RMS voltage within each 3-second period are assessed over successive window widths of 12 cycles (see Section 3.8).

Occasional power system operating conditions: Under occasional operating conditions, the limit for rapid voltage changes at the point of evaluation for the customer facility must not exceed 2 times the allowable limit under general operating conditions.

2.4 FLICKER

The following limits apply to cyclic or repetitive voltage variations that may cause the illumination level of lighting to change repeatedly. These variations can be attributed to fluctuating loads such as arc or induction furnaces, electric welding machines, variable-power presses, winches, rolling mills, frequent motor start-ups, rapidly varying generator or wind turbine output, etc.

2.4.1 Simplified assessment

A customer with a facility referred to in Section 1.2 need not produce a detailed assessment of emissions for flicker propagated to the transmission system provided the facility-induced voltage variations under general operating conditions are below the limits in Table 9. The customer must, however, confirm in writing to Hydro-Québec the voltage variations produced by its facility, and the associated repetition rate, to demonstrate that the facility meets the limits below. These limits are for voltage variations (ΔV/V) resulting from all fluctuating customer facility loads. The limits depend on the number of variations per minute at the point of evaluation (variations less frequent than 0,17 times/minute are subject to the limits in Section 2.3.1 Table 8). If a customer facility has fluctuating loads capable of producing voltage variations simultaneously at a number of Table 9 repetition rates, the corresponding voltage variation limits must then be divided by $\sqrt[3]{x}$, where x is the total number of fluctuating loads involved.

Table 9 – Flicker limits – Simplified assessment

Repetition rate (variations/minute)	Voltage variation ΔV/V (%)
> 0,17 and ≤ 0,5	1,5
> 0,5 and ≤ 1	0,8
> 1 and ≤ 10	0,4
> 10 and ≤ 200	0,2
> 200	0,1

Note: A drop in voltage followed by a rise, or vice versa, counts as two voltage variations.

2.4.2 Detailed assessment

2.4.2.1 Determining limits

General operating conditions: If a facility referred to in Section 1.2 has fluctuating loads (e.g.: arc or induction furnaces, electric welding machines, winches, rolling mills, variable-output generators or wind turbines) that exceed the limits set out in Section 2.4.1, the customer must provide Hydro-Québec with a detailed emission study for flicker caused by its facility using the method described in Section 3. The customer must thus demonstrate that its facility is designed to comply with the limit under general operating conditions.

Hydro-Québec will determine the flicker emission limit that applies to each customer facility based on the characteristics of the system under study and on the guidelines in reference [5]. This limit is set by allocating a portion of the total allowable flicker level in the system, based on the ratio of customer reference power to power system supply capacity using Equation 8 below. If Equation 8 gives a value below 0,3 for a customer facility, a minimum emission limit for flicker E_{Pst} = 0,3 will be allowed.

$$E_{Pst} = L_{Pst} \sqrt[3]{\frac{S_r}{S_{tP}}} \quad \text{(unitless number)} \qquad \text{(Eq. 8)}$$

Where:

E_{Pst} Flicker emission limit for the index P_{st} allowed at the customer facility under study

L_{Pst} Total allowable flicker level on the high-voltage system – L_{Pst} = 0,8 [5]

S_r Reference power for customer facility (in MVA) assessed using the method in Section 3.4

S_{tP} Total power of fluctuating loads supplied by the particular high-voltage system (in MVA) for the allocation of flicker level between system customers, taking into account future loads. Hydro-Québec will assess S_{tP} based on the characteristics of all fluctuating loads capable of being connected to the system under study and on the guidelines in reference [5].

NOTES ON APPLYING EQUATION 8:

12) The preceding limits must be compared to short-term flicker assessed over 10-minute aggregation intervals in accordance with IEC 61000-4-15 [7] and Class A requirements of IEC 61000-4-30 [3], adjusted for 120-V lamps. Emission levels must have a 95% daily value (95% probability of not exceeding allowable emission limits on a daily basis). Emission levels must have a 99% daily value not exceeding 1,25 times the allowable emission limits (see Section 3.9).

13) In some instances the pre-existing flicker level (BP_{st}) already on the power system due to all existing loads (ΣS_i) could be higher than the normal share, which is proportional

to $\sqrt[3]{(StP - \Sigma Si)/StP}$, and must be factored in to avoid exceeding the system's total allowable level. In Equation 8, it is then necessary to replace L_{Pst} by $\sqrt[3]{(L_{Pst}^3 - B_{Pst}^3)}$.

Occasional operating conditions: Customers for whom the ratio of system short-circuit power under general operating conditions to facility reference power (S_{sc}/S_r) is less than 30 must also submit an assessment of emission levels under occasional operating conditions to ensure that they do not exceed 1,5 times the allowable limits under general operating conditions.

3 Emission Level Assessment Methods

3.1 EMISSION STUDY

3.1.1 Need for an emission study

If a facility referred to in Section 1.2 does not meet the criteria for simplified assessment given in sections 2.1.1 or 2.2.1 or 2.4.1, the customer must provide Hydro-Québec with a detailed emission study for disturbances its facility produces in the transmission system to demonstrate that the facility is designed to comply with allowable emission limits based on assessment methods described in this document.

A change in reference power, modification of characteristics or addition of disturbance-producing equipment that may increase emission levels beyond allowable limits for the customer facility requires that the customer first conduct a new emission study (see Section 1.2). The expression “modification of characteristics” of an installation is taken to mean not only equipment characteristics or its size/power, but also any operating modification that may increase emission levels for disturbances. In particular, this includes modifications to the amplitude or repetition rate of active or reactive power demand, to the type of connection of disturbance-producing equipment, to the pulse number of converter units or phase relationship between units, to filter or capacitor characteristics, to three-phase characteristics affecting load or current imbalance, or to any modification to load cycles, operating or down times, repetition rate of disturbances, frequency of start-ups, etc., in short, any modification that may increase the emission level for disturbances beyond allowable limits.

3.1.2 General emission study requirements

The emission study for disturbances produced by a customer facility must be a study conducted by an engineer (whose title and practice are subject to the laws, codes and regulations applicable in Québec) and must take into account the methods and limits set out in this document. Section 4 covers the data and results that the emission study must contain. This study must be submitted to Hydro-Québec TransÉnergie for acceptance within the agreed timeframe, before the facility or disturbance-producing equipment is connected to the transmission system (see Section 5).

3.1.3 Review of the emission study

Hydro-Québec verifies customer emission study results solely to ensure that customer facilities are designed to comply with the emission limits allowed in the transmission system as set out in this document. Bear in mind that even if emission limits are met at the point of evaluation for connection to the Hydro-Québec transmission system, this does not guarantee that customer equipment will work properly. The disturbance may still be at too high a level within the customer facility to ensure that all equipment works adequately. More stringent emission limits may then be required on the customer facility side to meet specific customer equipment requirements.

The selection and design of equipment that complies with emission limits is the customer's responsibility. Any operating restrictions required for the customer to comply with emission limits must be recorded as conditions for connection and must be enforced.

When customer facilities are commissioned, Hydro-Québec may ask the customer to measure emission levels using a protocol approved by Hydro-Québec in order to validate data for the customer facility and emission study results. Measurements are not intended to replace emission studies prior to connecting to the power system or adding new disturbance-producing equipment.

Hydro-Québec may also take measurements at any time to verify that a customer facility complies with allowable emission limits.

3.2 POINT OF EVALUATION

The specified point of evaluation is a point located on the high-voltage transmission system side where emission levels from a given customer facility must be evaluated for comparison with allowable emission limits. If other customer facilities may be connected near the facility under study, the point of evaluation will generally be the connection point, or the high-voltage side of transformers if the connection point is on the low-voltage side of the transformers. The Transmission Provider may specify another point of evaluation depending on the specific power system characteristics and on other customer facilities potentially connected nearby.

The assessment is made at the nominal system voltage at the point of evaluation. It may, however, be necessary to consider parameters or characteristics of the system to either side of the point of evaluation in order to determine applicable limits or to assess emission levels. If a customer facility has more than one connection point to the transmission system, the assessment must be made at the point(s) specified by the Transmission Provider using any appropriate characteristics and reference power applicable to each point.

3.3 SYSTEM SHORT-CIRCUIT POWER (S_{SC})

System short-circuit power is used to determine values for applicable emission limits and to enable the customer to assess such emission levels as rapid voltage changes and flicker. The three-phase short-circuit power (S_{sc}) of the transmission system will be assessed by Hydro-Québec taking into account potential variations in generating station output, switching operations in response to variations in load, and equipment outages or down time corresponding to general or occasional operating conditions, as appropriate. Both existing and future systems must be considered. Note that for the detailed assessment of emission levels for harmonics, the customer must use the harmonic impedance loci as specified in Section 3.6.1.

In practice, the short-circuit level is often defined by means of the symmetrical short-circuit current (I_{sc}). For the purposes of this document, the three-phase short-circuit power (S_{sc}) can be calculated as the product of the three-phase short-circuit current (I_{sc}) and the nominal voltage (V_{nom}) at the point of evaluation times $\sqrt{3}$ $(S_{sc} = \sqrt{3} \bullet I_{sc} \bullet V_{nom})$. As for the system short-circuit impedance angle (θ), used in particular for calculating rapid voltage changes, it is generally defined as the ratio X/R provided with system short-circuit data $\{\theta = \arctan(X/R)\}$.

For customer facilities where emission levels must also be assessed under occasional operating conditions, system short-circuit power will be assessed by Hydro-Québec based on the worst-case equipment outage scenario (e.g., line and transformer outages) the statistical likelihood of which can be up to 5% of the time over one year. Both existing and future systems must be considered.

3.4 REFERENCE POWER (S_R) / REFERENCE CURRENT (I_R)

The reference power used in emission studies is the anticipated power of the customer facility in MVA. It provides the basis for determining the emission limits applying to a given facility and for assessing facility emission levels to verify that they comply with those limits. The reference current (I_r), also used for this purpose, is the line current calculated from the three-phase reference power (S_r) and the nominal system voltage (V_{nom}) at the point of evaluation for the customer facility $\{I_r = S_r / (\sqrt{3} \bullet V_{nom})\}$. For (single- and two-phase) unbalanced loads, the reference current is calculated by taking the mean value of the line currents considering all 3 phases.

3.5 OPERATING CONDITIONS TO BE CONSIDERED

In assessing emission levels for disturbances from its facility under general operating conditions, the customer must account for the most unfavourable coinciding conditions, and for frequent or prolonged (generally n-1) operating conditions, the overall statistical likelihood of which is greater than 5% of the time over one year. On the customer side, for instance, outages of a rectifier unit that is part of a higher pulse number facility are considered. On the transmission system side, for instance, such conditions are determined based on the mean outage rate of major equipment units. Both existing and future systems must be considered.

Other operating conditions specific to the local system or customer facility particularities may also be specified by Hydro-Québec in studying the connection of a customer facility. Those conditions must be considered by the customer in calculating its facility's emission levels.

For harmonics, imbalance and flicker, customers for whom the ratio of system short-circuit power under general operating conditions to facility reference power (S_{sc}/S_r) is less than 30 must also provide an assessment of emission levels for occasional operating conditions. For rapid voltage changes, a detailed study is required for all facilities. Occasional operating conditions are operating conditions (on the power system or customer facility side) that can produce higher emission levels up to 5% of the time over one year. They often correspond to abnormal operating conditions due to infrequent equipment outages or down time. On the customer facility side, it is necessary to consider equipment outages under degraded conditions that may occur occasionally and result in higher emission levels, e.g., an outage involving a number of rectifier units or involving filters or capacitors used to filter harmonics.

3.6 HARMONIC EMISSION LEVELS

Emission levels for harmonics must be assessed considering characteristic and non-characteristic harmonics of orders n = 2 to 50 caused by all disturbance-producing equipment in a customer facility. Emission limits for harmonic currents and telephone influence apply to line currents for the three phases, the worst phase having to meet the limits.

3.6.1 Assessing harmonic emission levels and impedance loci

Harmonic impedance loci serve as input to assess harmonic emission levels. System harmonic impedance loci at the point of evaluation for a facility are provided by Hydro-Québec for various system conditions corresponding to general and, if needed, occasional operating conditions.

To determine emission levels under general operating conditions, the system harmonic impedance loci are assessed considering all switching operations, and frequent or prolonged equipment outages the overall statistical likelihood of which is greater than 5% of the time over one year (all these conditions combined should thus give general operating conditions covering 95% of the time over a one-year period). Existing system conditions and those in the foreseeable future will be considered.

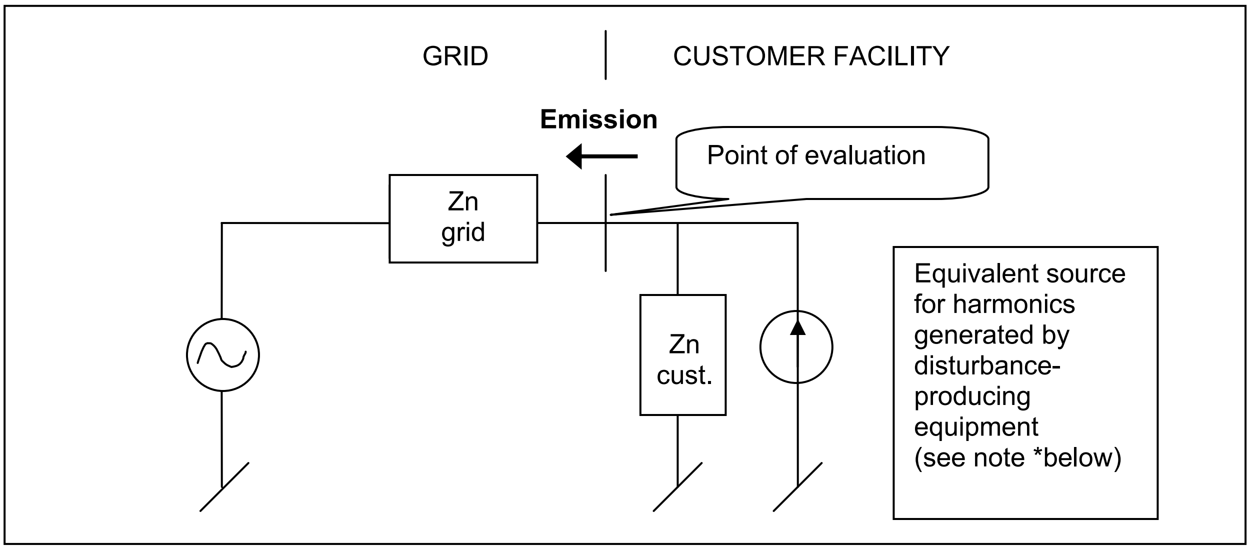
For customer facilities where emission levels must also be assessed under occasional operating conditions (where the ratio of short-circuit power under general operating conditions to reference power (S_{sc}/S_r) is less than 30), system harmonic impedance loci will be assessed by Hydro-Québec taking into account equipment outages (e.g., line and transformer outages) the overall statistical likelihood of which is up to 5% of the time over one year. Existing system conditions and those in the foreseeable future will be considered.

The impedance loci in the Hydro-Québec system ignore the effect of the customer facility but the customer must account for that effect in assessing its emission levels. The customer facility can interact with the power system, particularly resonance could occur between customer facility capacitors or filters and the power system. The customer facility must comply with harmonic emission limits once any amplifying effect of possible resonance is taken into account.

After having assessed the sources of (characteristic and non-characteristic) harmonics of orders n = 2 to 50 from disturbance-producing equipment in its facility, based particularly on sections 3.5 and 3.6.2, the customer must calculate maximum emission levels for harmonic currents at the point of evaluation by selecting, within the impedance loci, the value that maximizes the index calculated for each harmonic order. This implies that successive iterations must be made or an appropriate optimization algorithm be used to determine the combinations of system impedance (impedance loci) and customer facility impedance that maximize the harmonic current or index calculated (see Appendix A for more details).

Since the total demand distortion (TDD_c in Equation 2) combines the effect of several harmonic orders, it can be computed for various operating conditions using harmonic current emission levels corresponding to potential conditions or sets of coinciding conditions.

Figure 2 below is a simplified equivalent circuit where a current source represents the harmonics generated by disturbance-producing equipment in a customer facility. The emission level is the highest harmonic line current among the three phases at the point of evaluation expressed as a percentage of the reference current (I_n/I_r) (see Section 3.4).



* Note: This figure is a simplification, representing customer disturbance-producing equipment by an equivalent source of harmonic currents. This simplification is not intended to restrict the use of more detailed simulation models when required. For instance, it is possible to represent current sources with their angles for each rectifier group with their respective filters, or to customize this circuit and its parameters based on the results of detailed models of converters to assess non-characteristic harmonics.

Figure 1: Equivalent circuit for assessing harmonic emissions

The section below indicates operating conditions to be considered in assessing non-characteristic harmonics from disturbance-producing equipment under non-ideal conditions.

As mentioned earlier, since harmonic impedance varies in the power system and customer facility, computer programs and optimization algorithms are generally required to determine the harmonic impedance values that maximize calculated emission levels for each harmonic order (see Appendix A for more details).

Section 4 specifies the results that the emission study must contain.

3.6.2 Emission of non-characteristic harmonics

In practice, there is inevitably some degree of dissymmetry in the supply system and in customer facilities, which may produce so-called “non-characteristic” harmonics.

The customer must consider non-characteristic harmonics and their potential amplification through resonance in calculating emissions from its facility. At least the non-ideal conditions below must be considered by the customer so all harmonic sources are assessed in verifying that facilities meet emission limits. In some instances, other factors influencing the generation of harmonics must be considered.

- *Supply voltage imbalance*. A negative-sequence component in the three-phase supply voltage will generally produce non-characteristic harmonics that are odd multiples of three. Note that since such harmonics are not a zero-sequence component, they are not blocked by the transformer winding connection type. Non-ideal system operating conditions that must be considered in assessing harmonics include a steady-state voltage imbalance of 1% to 2% depending on supply system voltage [1], to which the customer must add the imbalance effect of its own facilities.
- *Lower pulse number*. Outages/imbalance of rectifier units belonging to a higher pulse number facility may produce non-characteristic harmonics of orders 5, 7, 11, 13, etc.
- *Converter transformers and asymmetric commutating impedance*. Manufacturing tolerances for transformation ratio (not exactly √3) and for reactance between pairs of transformers in a 12-pulse converter give rise to non-characteristic harmonics. Asymmetric commutating impedance between phases produces non-characteristic harmonics that also depend on transformer connections.
- *Firing angle asymmetries*. The variations of the valve firing instants can give rise to a wide spectrum of harmonics. The deviation in firing angles between valves depends on the particular design of the firing circuits.
- *Filter detuning*. When harmonic filters are needed to meet emission limits, their performance for harmonic emissions must also account for variations in tuning frequency, particularly those arising from:
    - *the ±0,2 Hz variation of the main power frequency that m*ay occur in steady-state operation, and

- o *filter detuning* due to imprecise component parameters, whether arising from manufacturing tolerances, initial mistuning or variations related to temperature or filter component ageing.

For dimensioning filters components, designers must generally account for disturbances that may originate in power system supply. Hydro-Québec has published a document on voltage quality characteristics and targets for its transmission system [1] that gives, for information purposes, disturbance levels that can be expected in the Hydro-Québec transmission system under normal operating conditions.

3.6.3 Measuring harmonic emission levels

It may be necessary to measure emission levels for harmonics from a customer facility, especially when they might exceed limits or to ensure that the facility complies with allowable emission limits. Measurements are not intended to replace emission studies prior to connecting to the power system or adding new disturbance-producing equipment.

The approach outlined below is of a general nature and will be supplemented as required by a measurement protocol approved by Hydro-Québec and established taking into account specificities of each customer facility and the system that supplies it.

Emission limits must be compared to the values of harmonic current indices (line current for the 3 phases) of orders $n = 2$ to 50 measured over 10-minute aggregation intervals (see also Section 2.1.2.1 Note 4) in accordance with IEC 61000-4-7 [2] and Class A requirements of IEC 61000-4-30 [3]. Emission levels must have a 95% daily value below allowable emission limits. This value is the maximum obtained when ignoring the top 5% of 10-minute values recorded during any given day. Emission levels must have a 99% daily value not exceeding 1,5 times the allowable emission limits. This value is the maximum obtained when ignoring the top 1% of 10-minute values recorded during any given day. These calculations are made discarding abnormal data flagged as specified in IEC 61000-4-30.

Continuous and rapidly fluctuating harmonics should be measured by the group and subgroup method rather than by harmonic components as explained in IEC 61000-4-7.

3.6.4 Telephone influence factor

An assessment of the telephone influence factor is not required for facilities meeting the criteria for simplified assessment under Section 2.1.1.

In other instances, the telephone influence factor $I{\cdot}T_{balanced}$ is computed using Equation 5 with harmonic current emission levels or orders $n = 2$ to 50 obtained using the methods described earlier. Since the telephone influence factor combines the effect of several harmonic orders, however, it can be computed for various operating conditions using harmonic current emission levels corresponding to potential conditions or sets of coinciding conditions. The worst case thus obtained must meet emission limits.

The emission study of a customer wishing to apply the specific $I \cdot T_{balanced}$ limit of 30000 $A_{weighted}$ must also include in its emission study the detailed assessment of the required parameters to demonstrate that at least one Table 5 acceptability criterion is met. The customer's assessment of these parameters must give a detailed survey of the geographic and electrical characteristics of telephone lines located in the vicinity (< 10 km) of the power lines affected. The Transmission Provider will determine the affected power lines that the customer must analyze to demonstrate that the specific limits apply. The lines to be analyzed may include lines or line sections that are electrically linked to the line(s) serving the customer facility under study and over which more than 50% of the critical harmonics emitted by that facility may flow.

Acceptability criteria parameters are assessed based on the definitions and references below.

L_{eq} Total equivalent length (in km) over which individual telephone lines run parallel to power lines affected by harmonics emitted by a customer facility. This is the total length of segments obtained by projecting perpendicularly from power lines to the telephone lines affected using the methods described in sections 5.128 to 5.138 of reference [8].

S_{min} Minimum equivalent distance separating the power lines and affected telephone lines. This is the shortest equivalent distance separating line segments obtained using the methods described in sections 5.128 to 5.138 of reference [8].

ρ_{eq} Equivalent soil resistivity at 1000 Hz along the power lines affected. Equivalent resistivity assumes a two-layer soil and is calculated based on reference [9], Vol. II, Section 4.1.11.2, pp. 171–175.

Z_m Mutual impedance in ground mode at 1000 Hz between the individual telephone lines and the power lines affected. This is the cumulative mutual impedance of individual telephone line segments. For each telephone line segment, Equation 5-40 in reference [8] is used to calculate the mutual impedance at 1000 Hz.

3.7 EMISSION LEVELS FOR LOAD IMBALANCE

Emission limits apply to customer facility load or current imbalance due to all customer facility unbalanced loads and potentially causing power system voltage imbalance. The imbalance here involves the negative-sequence component of current or voltage calculated using the symmetrical component method. Emission limits for current imbalance apply to line currents for the three phases at the point of evaluation.

For the simplified assessment, Section 2.2.1 refers to the value of the single-phase load equivalent to the load or power of a facility. Two simple examples are given below.

- For a facility consisting of a single-phase load totalling 2 MVA with a phase-neutral or phase-phase connection, the equivalent single-phase load is 2 MVA
- For a facility whose power on the three phases is either 10-12-10 MVA or 12-10-12 MVA, the equivalent single-phase load is 2 MVA, assuming the three phases have a similar power factor.

In less obvious cases, it is better to calculate the negative-sequence component of current using Equation 9 below and use the alternative criterion mentioned in Section 2.2.1, which consists in calculating the ratio (I_{neg}/I_{sc} in %).

3.7.1 Assessment of unbalanced load current

An unbalanced system can be assessed using the symmetrical component method. The customer whose facility consumes or produces power unbalanced between the three phases must assess the 60-Hz unbalanced current (negative-sequence component) produced by that facility given its operating characteristics (see also Section 3.5).

A simple single-phase load connected line-to-line, for instance, has a negative-sequence current equal to 0,577 times the single-phase load current. The negative-sequence current can generally be determined from the line currents at the point of evaluation using the following equation:

$$I_{neg} = \frac{1}{3}\left(I_A + a^2 I_B + a I_C\right) \qquad \text{(Eq. 9)}$$

Where:

I_{neg}	Negative-sequence component of the current corresponding to the customer facility load (or power) imbalance at the point of evaluation
I_A, I_B, I_C	Line current for the three phases A, B and C respectively, measured at the facility's point of evaluation or connection point
a	Vector operator for transformation into symmetrical components such that: $a = 1\,e^{j120^\circ}$ and $a^2 = 1e^{j240^\circ}$

For complex cases, assessing imbalance requires appropriate computer tools and models.

Note that these emission limits do not apply to negative-sequence currents arising from power system voltage imbalance and thus not due to unbalanced customer facility load or current.

3.7.2 Measuring emission levels for load imbalance

It may be necessary to measure emission levels for customer facility imbalance, especially when they might exceed limits or to ensure that a facility complies with allowable emission limits. Measurements are not intended to replace emission studies prior to connecting to the power system or adding new disturbance-producing equipment.

The approach outlined below is of a general nature and will be supplemented as required by a measurement protocol approved by Hydro-Québec and established taking into account specificities of the facility and the system that supplies it.

Emission limits must be compared to the facility's current imbalance factor (Equation 6) assessed over 10-minute aggregation intervals in accordance with IEC 61000-4-30 [3], adapting information on measuring negative-sequence voltage imbalance to the measurement of negative-sequence current. Limits for imbalance relate to 60-Hz systems. Emission levels must have a 95% daily value below allowable emission limits. This value is the maximum obtained when ignoring the top 5% of 10-minute values recorded during any given day. Measured levels must have a 99% daily value not exceeding 1,5 times the allowable emission limits. This value is the maximum obtained when ignoring the top 1% of 10-minute values recorded during any given day. These calculations are made discarding abnormal data flagged as specified in IEC 61000-4-30.

3.8 EMISSION LEVELS FOR RAPID VOLTAGE CHANGES

Emission limits apply to rapid RMS voltage changes caused by all fluctuating loads in a customer facility. Rapid voltage changes more frequent than 10 times per hour are subject to emission limits for flicker, covered in Section 2.4. Emission limits for rapid voltage changes apply to voltages for all three phases and the most strongly affected phase must comply with the limits. As mentioned in Section 2.3.1, rapid voltage changes are intermittent disturbances and must thus be assessed based on maximum values rather than statistical levels over time.

3.8.1 Assessment of rapid voltage changes

The customer whose facility has fluctuating loads must submit an emission study for the rapid voltage changes produced by all facility loads, taking their characteristics into account (see also Section 3.5). Hydro-Québec will provide the customer with short-circuit levels and other necessary power system data at the point of evaluation (see Section 3.3). Emission levels for rapid voltage changes must be assessed for both general operating conditions and occasional operating conditions as stipulated in Section 2.3.1.

In the simple case of motor or equipment start-ups where reactive power variations are dominant, the rapid voltage change is expressed by:

$$\frac{\Delta V}{V} = \frac{\Delta Q_{max}}{S_{sc}} \cdot 100\% \qquad \text{(Eq. 10)}$$

In the case of simultaneous variations of active and reactive power, the rapid voltage change is approximated by:

$$\frac{\Delta V}{V} = \frac{\Delta P \cos\theta + \Delta Q \sin\theta}{S_{sc}} 100 \quad (\%) \qquad \text{(Eq. 11)}$$

Where:

ΔP, ΔQ Variations in customer facility three-phase active and reactive power (MV, MVAR). Situations where active and reactive power variations have opposite effects on voltage can be covered by assigning different signs in Equation 11.

θ Angle of supply system short-circuit impedance, generally given by the ratio X/R such that $\theta = \arctan(X/R)$

S_{sc} System three-phase short-circuit power at the point of evaluation (MVA) (see Section 3.3)

In the case of unbalanced loads, calculations must be made using appropriate simulation software.

3.8.2 Measuring emission levels for rapid voltage changes

It may be necessary to measure emission levels for rapid voltage changes caused by a customer facility, especially when they might exceed limits or to ensure that the facility complies with allowable emission limits. Measurements are not intended to replace emission studies prior to connecting to the power system or adding new disturbance-producing equipment.

The approach outlined below is of a general nature and will be supplemented as required by a measurement protocol approved by Hydro-Québec and established taking into account specificities of the facility and the system that supplies it.

The following method of measuring rapid voltage changes is based on report IREQ 99-220 [10]. The method involves calculating the difference between minimum and maximum RMS voltage observed over successive 3-second periods, provided the RMS values remain within ±10% of the nominal voltage. Values of the RMS voltage within each 3-second period are measured consecutively over window widths of 12 cycles. Each voltage variation is expressed as a percentage of the average RMS voltage recorded during the 9 seconds preceding the end of each 3-second observation period. These measured values must comply with the emission limits specified in Section 2.3.1.1. By simultaneously measuring variations in customer load current, it is possible to correlate load variations and measured voltage variations.

3.9 *EMISSION LEVELS FOR FLICKE*R

Emission limits apply to flicker caused by all fluctuating loads at a given facility. Voltage variations less frequent that 10 times per hour are subject to emission limits for rapid voltage changes, dealt with in the preceding section. Emission limits for flicker apply to voltages for all three phases and the most strongly affected phase must comply with the limits.

3.9.1 Assessment of flicker

The customer whose facility has fluctuating loads must submit an emission study for the flicker level produced by all loads in its facility, taking their characteristics into account (see also Section 3.5). References [5] and [11] provide useful information for assessing flicker levels produced by fluctuating loads. Details on the assessment method to be used by the customer may be provided, if needed, as part of power system connection or integration studies. Hydro-Québec will also provide the customer with power system short-circuit levels or system impedance values at the point of evaluation to enable that assessment (see Section 3.3).

3.9.2 Measuring emission levels for flicker

It may be necessary to measure emission levels for flicker caused by a customer facility, especially when initial emission simulation data shows a possibility of exceeding limits or to ensure that the facility complies with allowable emission limits. Measurements are not intended to replace emission studies prior to connecting to the power system or adding new disturbance-producing equipment.

The approach outlined below is of a general nature and will be supplemented as required by a measurement protocol approved by Hydro-Québec and established taking into account specificities of each customer facility and the system that supplies it.

As mentioned earlier, emission limits must be compared to the short-term flicker index, P_{st}, measured over 10-minute aggregation intervals as specified in IEC 61000-4-15 [7] and Class A requirements of IEC 61000-4-30 [3], adjusted for 120-V lamps and excluding the effect of voltage sags, short interruptions or other interruptions on the power system. Measured levels must have a 95% daily value below allowable emission limits. This value is the maximum obtained when ignoring the top 5% of 10-minute interval values recorded during any given day. Measured levels must have a 99% daily value not exceeding 1,25 times the allowable emission limits. This value is the maximum obtained when ignoring the top 1% of 10-minute interval values recorded during any given day. These calculations are made discarding abnormal data flagged (e.g., abnormally high values due to system voltage dips) as specified in IEC 61000-4-30.

4 Emission Study Requirements

In cases where Hydro-Québec requires an emission study for disturbances caused by a customer facility, the study must be conducted by an engineer according to the methods described in Section 3. The study must contain emission level calculations and assessments for the customer facility and include all information needed to demonstrate that the facility is designed to comply with allowable emission limits.

The emission study a customer submits to Hydro-Québec must contain, at a minimum, the items below.

- A single-line diagram of facilities and key electrical characteristics of the customer's main equipment
- The reference power (S_r) of the customer facility and system short-circuit power (S_{sc}) at the point of evaluation
- General electrical characteristics and operating modes of disturbance-producing equipment (e.g., power and types of converters, pulse numbers, impedances, short-circuit power, power and types of motors, inrush current and load cycles)
- Assumptions underlying assessment of maximum levels for disturbance-producing equipment and their justification
- General electrical characteristics of any corrective equipment (e.g., harmonic filters, motor starters, current-limiting reactors and reactive power compensators)
- For harmonics, imbalance and flicker, customers for whom the ratio of short-circuit power under general operating conditions to reference power (S_{sc}/S_r) is less than 30 must provide an emission study covering both general and occasional operating conditions. For rapid voltage changes, this is required for any facility referred to in Section 1.2.

4.1 HARMONICS

The harmonic emission study that a customer submits to Hydro-Québec must contain the data below.

- Relevant facility specifications, particularly regarding the characteristics of capacitor banks and filters, including assumptions regarding filter detuning and the phase relationship between converter units
- Potential resonance between customer capacitors, filters or cables and the power system

- Tables with the following data for harmonics of orders n = 2 to 50:
  - Harmonic current maxima for characteristic and non-characteristic orders generated by customer disturbance-producing equipment with the respective angular displacements in the case of high pulse number converters represented by a number of equivalent harmonic current sources
  - Customer facility harmonic impedance values (amplitudes and angles), particularly the effect of capacitors and filters, accounting for detuning, possible switching operations, etc.
  - System harmonic impedance values that maximize each harmonic current value determined from the resulting harmonic impedance loci as explained in Section 3.6.1
  - Emission levels for indices I_n/I_r at the point of evaluation for each harmonic order (characteristic and non-characteristic)
  - Emission levels for TDD_c under different operating conditions

- For the telephone influence factor, values of the following parameters and indices:
  - Table of the $I{\cdot}T_{balanced}$ emission level for each harmonic order under the various operating conditions in accordance with Section 3.6.4
  - If the customer wishes to use the Table 5 specific limit, the study must include detailed calculations for the parameter (L_{eq}, ρ_{eq}, S_{min} or Z_m) justifying the specific limit, with drawings showing the relative geographic location of telephone lines and affected power lines as described in Section 3.6.4.

4.2 LOAD IMBALANCE

The emission study for load imbalance that a customer submits to Hydro-Québec must contain the items below.

- List of power levels for unbalanced loads, their operating modes and connection specifications or characteristics
- Description of any mitigation measures
- Table of maximum emission levels for unbalanced currents (negative-sequence component) at the point of evaluation for the various operating modes

4.3 RAPID VOLTAGE CHANGES

The emission study for rapid voltage changes that a customer submits to Hydro-Québec must contain the items below.

- List of active and reactive power variations, and the characteristics of associated fluctuating loads with their respective repetition rates
- Description of mitigation measures and their effect on emission levels as well as any planned operating conditions or restrictions
- Table of emission levels for rapid voltage changes and their repetition rate at the point of evaluation, taking into account scheduled reactive compensator switching operations.

4.4 FLICKER

The emission study for flicker that a customer submits to Hydro-Québec must contain the items below.

- Description of the electrical and operational characteristics of fluctuating loads (e.g., for arc furnaces: short-circuit power and impedance levels, type of process, type of raw material used in the furnace, operating cycles, etc.; for motors: power, types of motors, starting current, frequency of start-ups, load cycles, etc.)
- List of power variations for fluctuating loads, with their associated repetition rates
- Table of the resulting voltage variations and the associated repetition rate at the point of evaluation
- Methods used to calculate the combined effect of fluctuating loads that produce flicker, justifying how and why they are used
- Resulting emission level for flicker at the point of evaluation as it relates to the allowable limit (E_{Pst}).

5 General Steps for Applying Limits

The following are general steps and may vary depending on the type of project. Detailed steps and schedules will be worked out during integration studies as part of the power system connection process.

- Early in the planning stage of a potentially disturbance-producing customer facility, Hydro-Québec will inform the customer of allowable emission limits for its connection to the transmission system.
- Once it is determined how the customer facility will be connected, Hydro-Québec will provide the customer with short-circuit levels (see Section 3.3) and, if necessary, the power system harmonic impedance loci at the point of evaluation.
- If a facility referred to in Section 1.2 meets the criteria for simplified assessment given in section 2.1.1, 2.2.1 or 2.4.1, the customer must confirm in writing to Hydro-Québec the total power of its disturbance-producing equipment and demonstrate that the criteria are met.
- If a facility referred to in Section 1.2 does not meet the criteria for simplified assessment given in section 2.1.1, 2.2.1 or 2.4.1, the customer must then conduct a detailed emission study for facility-produced disturbances in the transmission system to demonstrate that the facilities are designed to comply with allowable limits. This entails a study by an Engineer to assess emission levels propagating from the customer facility to the transmission system, conducted following Section 3 methods and reporting Section 4 data.
- If disturbance levels exceed any allowable emission limit, the customer must either change the facility's design or install corrective equipment in order to comply with emission limits. The emission study must describe and analyze the characteristics and performance of the corrective measures considered.
- The customer must provide Hydro-Québec with the above-mentioned study, including the results of emission level assessments (see Section 4), and any other information required to demonstrate that its facility is designed to comply with allowable limits or that any necessary corrective measures have been taken. This study must be submitted within the prescribed timeframe to Hydro-Québec TransÉnergie for acceptance, before the facility or new disturbance-producing equipment is connected to the power system.

- Based on information contained in the emission study, Hydro-Québec will verify that emission levels have been assessed following the prescribed methods and that they comply with the allowable limits specified in Section 2.
- Any operating restrictions required for the customer to comply with the limits must be recorded as conditions for connection and must be enforced.
- Hydro-Québec may request that the customer measure emissions following a protocol approved by Hydro-Québec and established taking into account specificities of each customer facility and the system that supplies it. These measurements could be required, in particular, to verify the validity of customer facility data and emission study results, or to verify that the facility complies with allowable emission limits. Note that these measurements are not intended to replace emission studies prior to connecting to the power system or adding new disturbance-producing equipment.
- Hydro-Québec reserves the right to take measurements at any time to verify that a customer facility complies with allowable emission limits.

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Appendix A
Assessing Maximum Harmonic Emission Levels Based on Impedance Loci

This appendix gives supplementary information and examples of possible methods for assessing as indicated in section 3.6.1 maximum emission levels for harmonic currents based on the impedance loci specified for the transmission system.

A.1 Depiction of harmonic impedance loci

Harmonic impedance loci are used to define the range of possible transmission grid impedances for harmonic orders subject to emission limits. Grid impedance may have any value on the edge of or within the loci. Grid harmonic impedance loci do not include the effect of the customer facility under study.

Transmission grid impedance loci are defined in the plane R ± jX and may be depicted using sectors, polygons or circles.

A.1.1 - Sectors

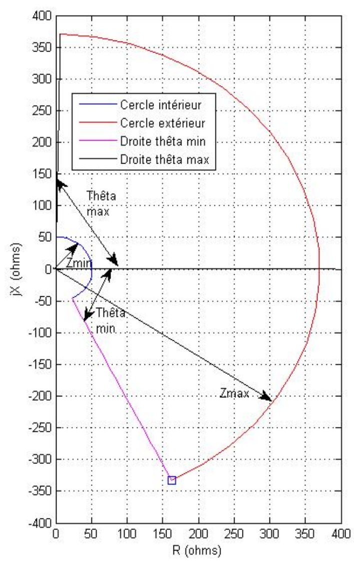


Figure A.1.1: Sector depiction of impedance loci

Grid impedance loci depicted as sectors are delimited by the following parameters for each harmonic order (see Figure A.1.1):

- Two arcs of circles having the origin as centre and radii of Z_{min} and Z_{max}
- Two straight lines connecting the Z_{min}-radius circle to the Z_{max}-radius circle along the minimum angle (theta min) and maximum angle (theta max).

A.1.2 - Polygons

Grid impedance loci may also be depicted as polygons to delimit more closely, when needed, impedance values at specific harmonic orders. Figure A.1.2 shows a six-sided polygon, the maximum number of sides generally being eight. The polygon is delimited using the coordinates of points R_i and jX_i for different harmonic orders given by Hydro-Québec in a table.

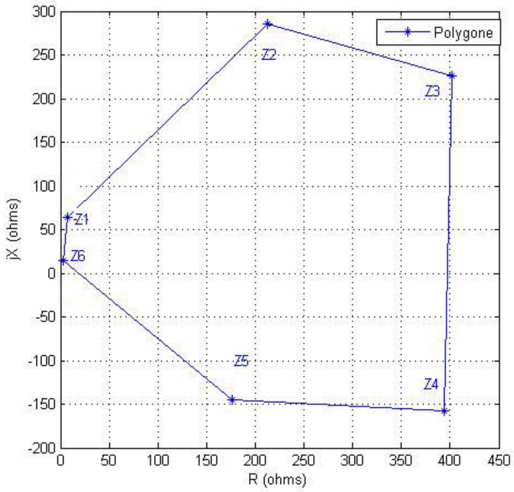


Figure A.1.2: Polygon depiction of impedance loci

A.1.3 – Circles

A circle is generally used for depicting together possible grid impedances for a number of harmonic orders. The circle is delimited by:

- A minimum resistance value (R_{min}) for a given range of harmonic orders
- A maximum angle (theta max) and minimum angle (theta min) for the impedance delimited by straight lines from their intersection with line R_{min} to their intersection with the circle
- The modulus of the maximum impedance forming a circle of diameter (Z_{max}) with its centre on the X-axis at (Z_{max}/2) as shown in Figure A.1.3.

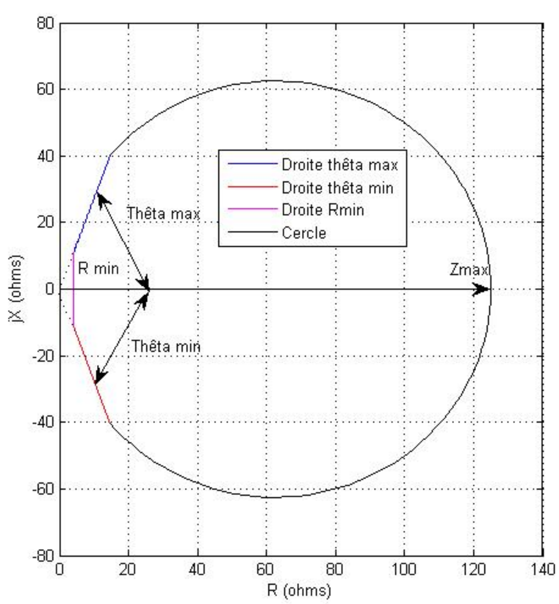
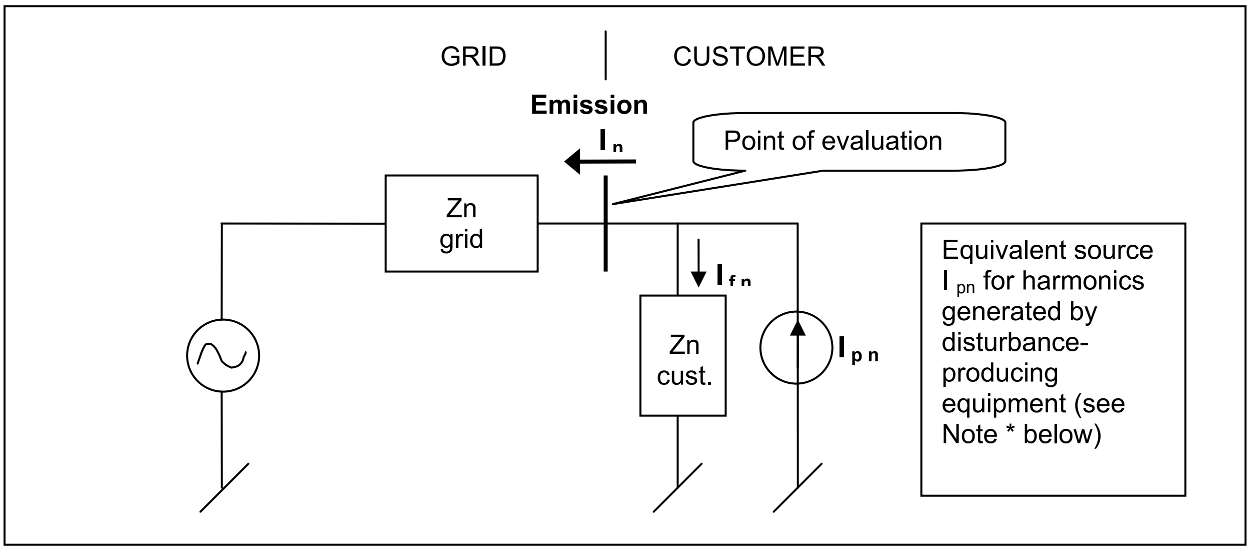


Figure A.1.3: Circle depiction of impedance loci

A.2 - Assessment of maximum emission levels for harmonic currents based on grid impedance loci

The customer facility (generator or load) connected or to be connected to the Hydro-Québec transmission system is represented simply by a Norton equivalent. Thus for each harmonic order, and if necessary for each customer facility operating condition to be assessed, an equivalent harmonic current source is taken to be in parallel with the customer facility harmonic impedance and the grid harmonic impedance specified by loci. As mentioned in the note below, this representation does not exclude the use of more detailed or customized models when required.



* Note: This figure is a simplification, representing customer disturbance-producing equipment by an equivalent source of harmonic currents. This simplification is not intended to restrict the use of more detailed simulation models when required. For instance, it is possible to represent current sources with their angles for each rectifier group with their respective filters, or to customize this circuit and parameters based on the results of detailed models of converters to assess non-characteristic harmonics.

Figure A.2.1 – Equivalent circuit for assessing harmonic emissions

Where:

- **I_{pn}** – Equivalent source of n^{th} order harmonic from customer disturbance-producing equipment
- **I_{fn}** – Current of n^{th} order harmonic in filters, capacitors or other customer equipment
- **I_n** – Emission of n^{th} order harmonic current onto the grid
- **$Zn_{cust.}$** – Equivalent impedance of n^{th} order harmonic of the customer facility
- **Zn_{grid}** – Grid harmonic impedance loci where the impedance value maximizing the emission of n^{th} order harmonic current must be found

In this equivalent representation, the emission level of n^{th} order harmonic current (I_n) propagating onto the grid consists of a current divider such that :

$$I_n = \frac{Zn_{cust.}}{Zn_{grid} + Zn_{cust.}} * I_{pn} \qquad \text{Eq. A2.1}$$

The maximum emitted current I_n for each harmonic order can be evaluated with Eq. A.2.1 by choosing in the grid impedance loci the value that maximizes the calculation. Maximizing must be done, if needed, for various customer facility operating conditions and the highest value obtained is the harmonic current emission level for each order.

Two methods are given below, both requiring the use of appropriate algorithms. Other methods may exist to achieve the objective above.

A.2.1 Iterative method

This approach involves scanning the grid harmonic impedance loci using an iterative loop to find the impedance value in loci Zn_{grid} that maximizes the emission of n^{th} order harmonic current (I_n) in Eq. A.2.1.

A2.2 Geometric method

In Eq. A.2.1, taking a single value of $Zn_{cust.}$ at a time for a given case, the numerator is constant. Maximizing the harmonic current emission (I_n) then simply involves minimizing the modulus of denominator $|Zn_{grid}+Zn_{cust.}|$:

$$\left|Zn_{grid} + Zn_{cust.}\right| = \sqrt{\left(\mathrm{Re}\left(Zn_{grid}\right) + \mathrm{Re}\left(Zn_{cust.}\right)\right)^2 + \left(\mathrm{Im}\left(Zn_{grid}\right) + \mathrm{Im}\left(Zn_{cust.}\right)\right)^2} \qquad \text{Eq. A.2.2}$$

It may also be shown that minimizing the sum of the two preceding vectors is equivalent to **finding the minimum distance**, in a complex plane, **between the points in loci Zn_{grid} and the corresponding point of negative vector $Zn_{cust.}$** (i.e., : $-Zn_{cust.}$= (Re($-Zn_{cust.}$), Im($-Zn_{cust.}$))). Actually, the distance between any two points $Z_1=(x_1,y_1)$ and $Z_2=(x_2,y_2)$ is given by:

$$d = \sqrt{\left((x_1 - x_2)^2 + (y_1 - y_2)^2\right)} \qquad \text{Eq. A.2.3}$$

Replacing Z_2 by the negative vector of $Zn_{cust.}$ in the equation above gives:

$$d = \sqrt{\left(\left(\mathrm{Re}\left(Zn_{grid}\right) - \mathrm{Re}\left(-Zn_{cust.}\right)\right)^2 + \left(\mathrm{Im}\left(Zn_{grid}\right) - \mathrm{Im}\left(-Zn_{cust.}\right)\right)^2\right)} \qquad \text{Eq. A.2.4}$$

Eq. A.2.2 is equivalent to Eq. A.2.4 but the latter gives a geometric meaning to the solution sought, i.e., minimizing the modulus in Eq. A.2.2 amounts to minimizing the distance between point $-Zn_{cust.}$ and grid harmonic impedance loci Zn_{grid}. For the conditions described, the grid impedance value that minimizes the distance between these points thus determines the maximum harmonic current in Eq. A.2.1.

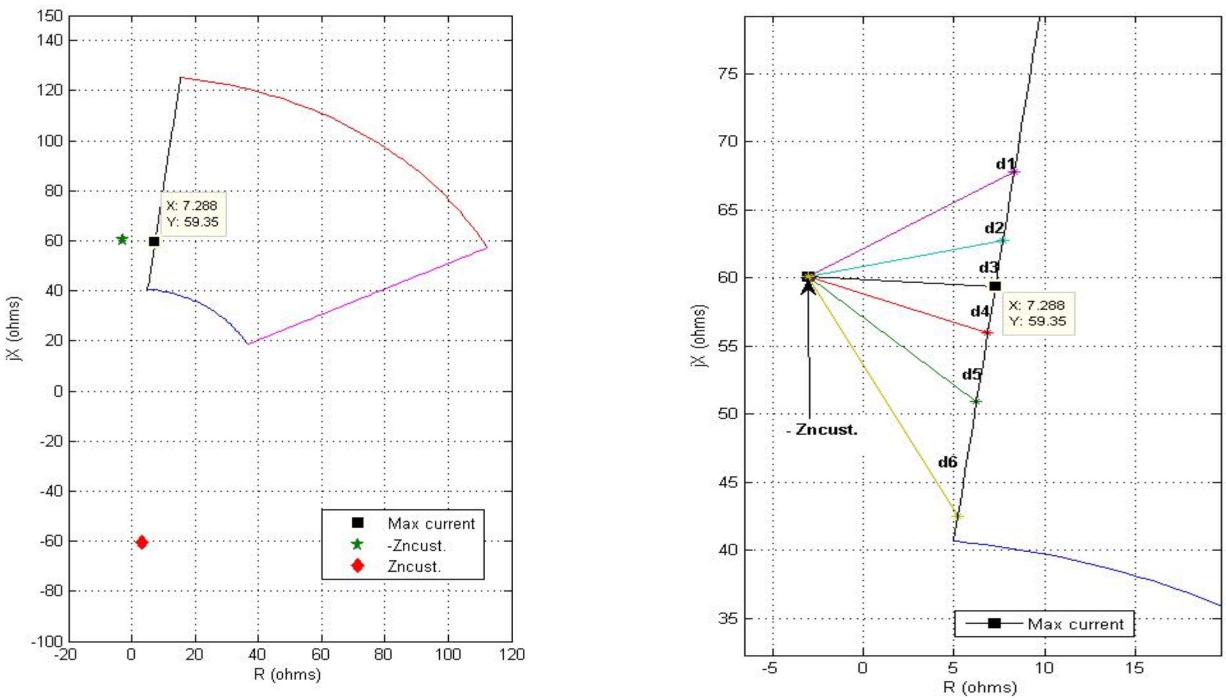
Assuming that the real part of customer facility harmonic impedance is positive, point $-Zn_{cust.}$ is to the left of the imaginary axis in the complex plane, and the shortest distance between that point and the grid impedance loci is thus found on the edge of the impedance loci whether it be delimited by a sector, a polygon or a circle.

A2.3 Example

Figure A.2.2 shows an example of grid impedance loci depicted as a sector (left graph).

After scanning the loci in question to maximize the harmonic current emission given in Eq. A.2.1, the grid impedance is found to correspond to a point on the edge of the sector at 7,288+j 59,35 ohms (Figure A2.2, left graph). Intuitively this case is close to one of resonance since the imaginary parts of Zn_{grid} and $Zn_{cust.}$ are similar.

The geometric method that applies Eq. A.2.4 to minimize the distance between the points of loci Zn_{grid} and point $-Zn_{cust.}$ gives the same result (right graph). Among the distances d1 to d6 plotted on the graph, it can be seen that the shortest, d3, gives the same grid impedance point (7,288, 59,35) as obtained by scanning to maximize the current.



Distances (unitless)	
d1	1,369
d2	1,102
d3	1,031
d4	1,070
d5	1,304
d6	1,944

Figure A.2.2: Example results for two methods of finding the grid impedance maximizing harmonic current