MEASUREMENT METHODS OF THE CHARACTERISTICS AND TARGET VALUES OF THE VOLTAGE QUALITY SUPPLIED BY HYDRO-QUEBEC SYSTEM

Report no.: IREQ-99-220

Revision #1

This document is a translated version of the French document dated December 1, 2000 entitled "Méthodes de mesure des caractéristiques et cibles de qualité de tension" IREQ-99-220 révision 1.

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

MEASUREMENT METHODS OF THE CHARACTERISTICS AND TARGET VALUES OF THE VOLTAGE QUALITY SUPPLIED BY HYDRO-QUEBEC SYSTEM

Summary

This document deals with the measurement methods and the interpretation of results for the parameters which characterize power quality supplied by Hydro-Québec power system. It presents approximate methods which use analog devices and more precise methods which require the use of specialized devices of a more recent design.

Preamble

The measurement methods presented in this document are based on International Electrotechnical Commission (IEC) standards, especially IEC 61000-4-7 [3] on harmonics, IEC 61000-4-15 [4] on flicker, and the recommendations of CEA Guide 220D711 [2] on power quality measurement surveys.

Moreover, IEC Working Group 77A WG9 is currently preparing a new standard, IEC 61000-4-30, "Power quality measurement methods," which should be approved in a few years. The methods described in this standard will allow comparable results to be obtained regardless of the measuring instrument model or manufacturer or the environmental conditions in which the instruments are required to operate in.

The standards which are currently being drawn up, especially IEC 61000-4-30, will eventually complement or replace the methods described in this report. In the meantime, this report provides the information needed for a transition to take place between the instruments currently available or in use on the power system and the new devices required to meet standardization requirements.

Object

This report deals with the measurement of power quality characteristics and target values described in references [1] and [5].

TABLE OF CONTENTS

1.0 STEADY-STATE VOLTAGE

1.1 Analog measurement method

The steady-state rms voltage can be measured using a “true rms” analog converter which provides a direct-current temporal signal that is proportional to the rms system voltage. The converter’s signal must be smoothed with a first-order RC filter with a 5-min time constant. The maximum and minimum values at each 10-min interval of the signal integrated by the filter must be recorded if they exceed 50% of the nominal rms voltage V_d. These values are used to calculate the rms voltage deviations from the nominal voltage level V_d. These deviations are named overvoltage *IRO* if they exceed the nominal voltage level or undervoltage *IRU* otherwhile, (see equations 1.3, 1.4 and 1.5). Weekly recordings are then used to perform a statistical calculation of the variations corresponding to the percentile rank of 95%, 99% or 99.9% of the recordings. System voltage characteristic level may thus be exceeded in 5% or 1% of the cases, depending on whether the percentile being considered is 95% or 99% (see section 1.4 for the statistical analysis method).

1.2 Numerical measurement method

The voltage $U(t)$ must first be sampled on windows lasting at least 8 but preferably 12 cycles. The time between the leading edge of the first sampling pulse and the leading edge of the last sampling pulse in each sampled window shall be equal to the duration of the specified number of cycles (eg. 12 cycles, see Figure 1) of the power system, with a maximum permissible error of ± 0.03%. In practice, several power system phenomena can produce phase-shift variations which can from time to time

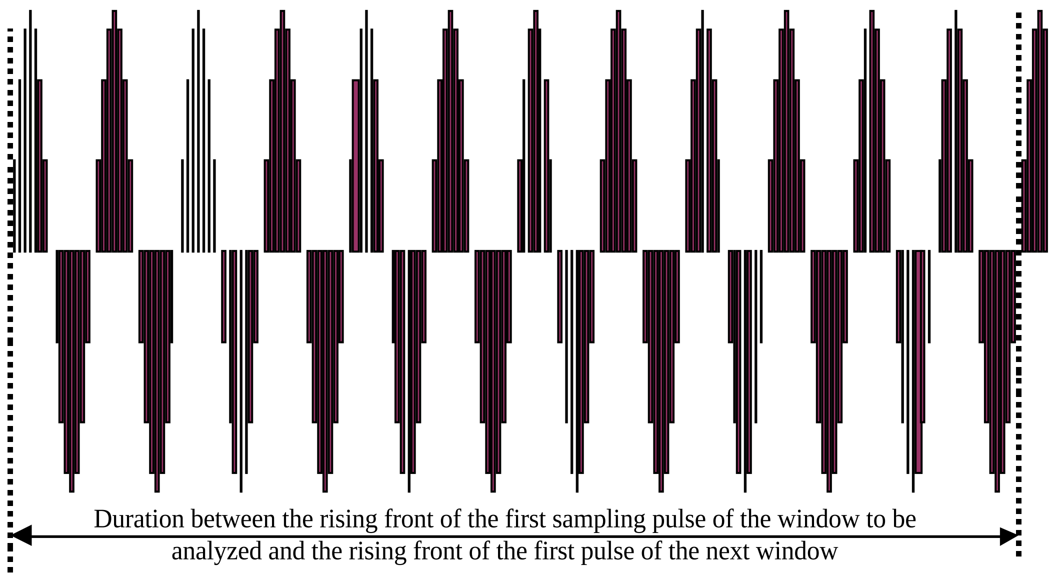

Figure 1: Sampling pulses for a 12-cycle window

significantly decrease or increase the duration of the window to be analyzed. The voltage values assessed during these time periods must be tagged and excluded from the assessment if there is a difference of more than 0.03% between the window width and the number of cycles .

These samples are then used to calculate the instantaneous rms voltage *ISV*, using one of the two following methods:

- root mean square of the *U*(t) samples:

$$ISV = \sqrt{\frac{\sum_{t=1}^{t=NB} U(t)^2}{NB}} \tag{1.1}$$

where NB = the number of samples obtained per window that is equal to or greater than 8 cycles (preferably 12 cycles). This amount must be equal to or greater than 512.

- root-sum-square of the component of the rms voltage at the fundamental frequency IVH_1 and that of each harmonic and interharmonic order IVH_n of *U*(t):

$$ISV = \sqrt{\sum_{n=1}^{n?16} IVH_n^2} \tag{1.2}$$

where n = the order of components (harmonic and interharmonic) obtained by Fourier transform.

The resulting instantaneous rms voltage *ISV* is used to calculate upward or downward deviation from the nominal value provided that the rms value is greater than 50% of the nominal rms voltage V_d. Once validated, it is used to determine the variation of the overvoltage *IRO* and unvervoltage *IRU* in relation to the nominal rms voltage V_d, as follows:

$$ISV_d = \frac{ISV - V_d}{V_d} \leftrightarrow 100\% \; ; \tag{1.3}$$

$IRU = - ISV_d$ if $ISV_d < 0$ and $IRU = 0$ if $ISV_d \geq 0$; (1.4)

$IRO = ISV_d$ if $ISV_d > 0$ and $IRO = 0$ if $ISV_d \leq 0$. (1.5)

At least one *IRU* and one *IRO* value must be recorded per second to calculate the rms level of $U_{10min\text{-}under}$ undervoltage and $U_{10min\text{-}over}$ overvoltage variations which characterize each 10-min interval during the measurement period (equations 1.6 and 1.7).

$$U_{10\,\min-under} = -\sqrt{\sum_{i=1}^{i=N} \frac{IRU_i^2}{N}} \qquad (1.6)$$

$$U_{10\,\min-over} = \sqrt{\sum_{i=1}^{i=N} \frac{IRO_i^2}{N}} \qquad (1.7)$$

where N ≥ 600 = the number of *IRO* or *IRU* recordings made at each 10-min interval.

1.3 Precise measurement method

The precise voltage measurement method takes into account the overvoltages and undervoltages which precede the 10-min interval being assessed. When the voltage varies by more than 5% during each 10-min interval or that the variations measured approach the target values within 2% of the nominal rms voltage, the method of synchronized intervals described in the CEA guide [Ref. 2] should be used.

1.4 Statistical analysis method

Weekly recordings of $U_{10min\text{-}under}$ or $U_{10min\text{-}over}$ are used for the statistical calculations required to assess the weekly values of the overvoltage and undervoltage deviations. The method used to determine the 10-min intervals described in the CEA guide [Ref. 2] should be used. The absolute values of the recordings are classified in increasing order. Each value in the series is then linked to a percentile rank[note 1]. The value of the $U_{10min\text{-}under}$ levels and that of the $U_{10min\text{-}over}$ levels found in the desired percentile rank (95, 99 or 99.9 percentile[note 2]) is compared against the target value of the voltage characteristic [1] and [5].

2.0 HARMONIC VOLTAGES

2.1 Method for measuring harmonic voltages

The evaluation of each harmonic order requires that the voltage be recorded in windows with a constantly adjustable width to remain within the tolerance of ±0.03% of the 12-cycle duration at the actual system frequency in accordance with IEC-61000-4-7 [Ref. 3 – clause 1.2]. It is recommended that a spectral analysis of these windows be done for each consecutive period of less than 500 ms. The

---

Note 1: "percentile rank": Each value of a quantitative characteristic which shares the range of the values in one hundred subsets of equal samples. (The first percentile is such that one one-hundredth of the values is below it, etc.)

Note 2: "percentile": The value of the statistical variable that marks the boundary between any two consecutive intervals in a distribution of 100 intervals each containing one percent of the total data set. The values dividing the data into one hundred equal parts are called percentiles.

recordings must be done at a sampling rate of more than 2047 samples per window. Each sample of a waveform cycle is compared against the sample of the previous cycle to ensure that the voltage transients, sags or temporary overvoltages do not appear in the data. The procedure used for the comparison is described in reference [2]. The results of the measurement window are valid if the amplitude of the fundamental voltage of each phase being measured exceeds the nominal rms voltage by 50%.

The assessment of each harmonic order IVH_n must comply with the CEA guide [Ref. 2]. This protocol describes the calculation method used to determine the rms level of the voltage amplitude at the frequency of the harmonic order n over the 10-min interval $IVH_{n(10\ min)}$.

2.2 Statistical analysis method

The root mean square of the voltage amplitude at each harmonic rank $IVH_{n(10min)}$, calculated at each 10-min intervals for 7 consecutive days is used for the statistical calculations required to assess the weekly level of harmonics which does not exceed 95% of the cases. The method to determine the 10-min intervals described in the CEA guide [Ref. 2] must be used. To do so, weekly recordings are categorized in increasing order. Each value in the series is then linked to a percentile rank, from the smallest to the highest. The $IVH_{n(10min)}$ value which is found at the 95th percentile is compared to the target value of the voltage characteristic [1] and [5].

3.0 VOLTAGE UNBALANCE

3.1 Method for measuring voltage unbalance

The assessment of the level of voltage unbalance *VUF* requires simultaneous recordings of the voltages of each of the three phases. This *VUF* level is calculated based on the fundamental component of the voltages , and of the grounded three-phase system. If the system being operated is ungrounded, the voltages between the phases , and are then measured. Depending on the measured voltages, one of the two following equations will be used to determine the power system's *VUF* level:

$$VUF = \left| \frac{\left(\vec{U}_{a-n} + \vec{h}^2\vec{U}_{b-n} + \vec{h}\vec{U}_{c-n}\right)}{\left(\vec{U}_{a-n} + \vec{h}\vec{U}_{b-n} + \vec{h}^2\vec{U}_{c-n}\right)} \right| \leftrightarrow 100\% \tag{3.1}$$

$$VUF = \left| \frac{\vec{U}_{a-b} - \vec{h}\vec{U}_{b-c}}{\vec{U}_{a-b} - \vec{h}^2\vec{U}_{b-c}} \right| \tag{3.2}$$

$$\vec{h} = -\frac{1}{2} + \frac{\sqrt{3}}{2} j \quad \text{et} \quad j = \sqrt{-1}$$

Equations 3.1 and 3.2 are used for the voltage vectors but the measurement may also be done using the phase-to-phase voltage modulus with one of the following equations:

$$VUF = \sqrt{\frac{1-\sqrt{3-6\beta}}{1+\sqrt{3-6\beta}}} \times 100\% \tag{3.3}$$

$$\beta = \frac{U_{a-b}^4 + U_{b-c}^4 + U_{c-a}^4}{\left(U_{a-b}^2 + U_{b-c}^2 + U_{c-a}^2\right)^2} \tag{3.4}$$

The voltage unbalance is then calculated if the modulus of each voltage value exceeds the nominal rms voltage by 50%. The voltage may be recorded using an analog-to-digital converter at a sampling rate greater than 32 samples per second. The modulus and angle of the fundamental voltage can be calculated by Fourier transform on a window with at least 8 cycles (preferably 12).

The relative accuracy of the amplitude and the phase angle between the recorder's channels has a direct influence on the accuracy of the voltage unbalance measurement and should therefore be checked. This is done by connecting the recorder's three channels to the same phase. The maximum difference of the modulus and the angle between two of the three voltage levels recorded should not exceed 0.07% of the average of the three voltage levels and 0.05°. The device must be calibrated if one of the two criteria is not met (amplitude error of 0.07% or uncertainty degree of 0.05°).

Three measuring transformers with an accuracy class of at least 0.6% may be used in the measuring chain if they are identical (same manufacturer and model) and each one supplies the same number of devices of the same model. Two-elements measuring systems, consisting of two voltage transformers connected in an open-delta configuration, may provide an acceptable level of accuracy if the following conditions are met:

- the transformers are identical (same manufacturer and model);
- they supply the same number of devices of the same model;
- their primary windings are connected between phases;
- they do not supply any load on the open-delta side.

The transformer connection in an open-delta configuration for measuring units with two-and-a-half elements usually supplies phase-to-ground voltage for two phases of the system. This type of connection cannot be used to assess voltage unbalances.

Special attention must be given to how measurement transformers are connected due to the phase shifting caused by wye-delta or delta-wye connections. It is important to ensure that phase-to-neutral or phase-to-phase voltages measured on the secondary side of measurement transformers truly reflect the system voltage levels which are being measured.

The assessment of the intervals related to voltage unbalances must comply with the CEA guide [Ref. 2]. This protocol describes the calculation method used to determine the rms voltage unbalance level over the 2-h interval VUF_{2h}.

3.2 Statistical analysis method

The root mean squares of at least 200 voltage unbalance values VUF_{2h}, sampled every 2 h for 7 consecutive days are used to perform the statistical calculations required to assess the weekly unbalance level which is not exceeded 95% of the time. The method used to determine the 2-h intervals described in the CEA guide [Ref. 2] must be used. To do so, the weekly recordings are categorized in increasing order. Each value in the series is then linked to a percentile rank, from the smallest to the highest. The VUF_{2h} level value which is found at the 95th percentile is compared to the target value of the voltage characteristic [1] and [5].

4.0 FLICKER

4.1 Method for measuring flicker

The flickermeter was initially designed to measure flicker produced by a 60-W, 230-V incandescent lamp. In 1986, after more than 10 years of testing, the flickermeter was standardized by the IEC (IEC 61000-4-15, revised in 1997) [4]. However, less flicker is produced by a 120-V incandescent lamp than by a 230-V one. Recent research conducted by the International Union for Electroheat led to the necessary modifications being made to the flickermeter so that the flicker produced by a 120-V lamp could be assessed. These modifications are based on the values of the F(s) transfer function coefficients which link the fluctuations in voltage and the steady-state flicker level. The transfer function corresponds to the flicker weighting filter which is rendered by the following equation:

$$F(s) = \frac{k\omega_1 s}{s^2 + 2\lambda s + \omega_1^2} \frac{1 + s/\omega_2}{(1 + s/\omega_3)(1 + s/\omega_4)} \qquad (4.1)$$

An analytical comparison of the flicker produced by 230-V and 120-V lamps is shown in Figure 2 and Tables 1 and 2.

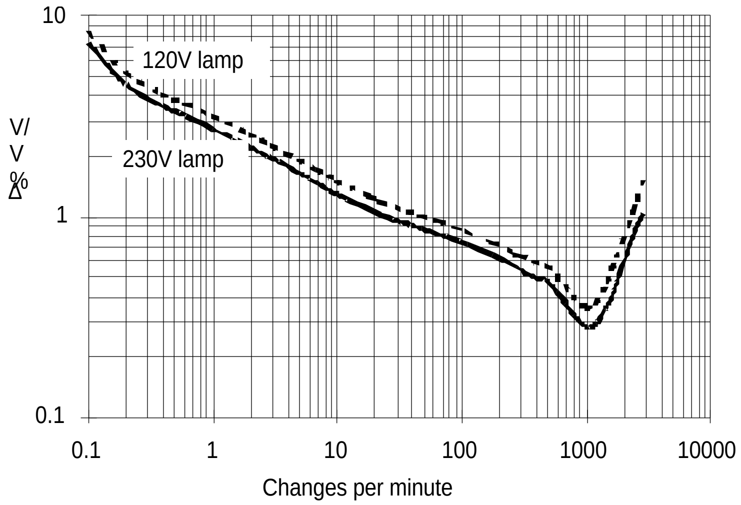

Figure 2: Rectangular voltage fluctuations for P_{st} = 1 p.u.

Table 1: Flicker weighting filter coefficients

Coefficients	Voltage	
	230 V	120 V
k	1.74802	1.6357
λ	2·π·4.05981	2 π·4.167375
ω_1	2·π·9.15494	2 π·9.077169
ω_2	2·π·2.27979	2 π·2.939902
ω_3	2·π·1.22535	2 π·1.394468
ω_4	2·π·21.9	2 π17.31512

Table 2: Comparison of the amplitudes of the fluctuations in the voltage supply on two incandescent lamps for a flicker severity level of P_{st} = 1

Variations per minute	Fluctuation frequency (Hz)	Variation related to the voltage ΔV/V (%) for a flicker severity level of $P_{st} = 1$	
		produced by a 230-V lamp	produced by a 120-V lamp
0.1	0.000833	7.4	8.202
0.2	0.001667	4.58	5.232
0.4	0.003333	3.54	4.062
0.6	0.00500	3.2	3.645
1	0.00833	**2.724**	**3.166**
2	0.01667	**2.211**	**2.568**
3	0.02500	1.95	2.250
5	0.04167	1.64	1.899
7	0.05833	1.459	1.695
10	0.0833	1.29	1.499
22	0.1833	1.02	1.186
39	0.3250	**0.906**	**1.044**
48	0.4000	0.87	1.0
68	0.5667	0.81	0.939
110	0.9167	**0.725**	**0.841**
176	1.4667	0.64	0.739
273	2.2750	0.56	0.650
375	3.1250	0.5	0.594
480	4.0000	0.48	0.559
585	4.8750	0.42	0.501
682	5.6833	0.37	0.445
796	6.6333	0.32	0.393
1020	8.5000	0.28	0.350
1055	8.7917	0.28	0.351
1200	10.000	0.29	0.371
1390	11.583	0.34	0.438
1620	13.500	**0.402**	**0.547**
2400	20.000	0.77	1.051
2875	23.9583	1.04	1.498

Tables 3 and 4 below, which have been extracted from IEC 61000-4-15 [4] and adapted for a 120-V lamp, are used to validate the response of a flickermeter at the block 4 output for sinusoidal and rectangular voltage fluctuations.

Table 3: Normal flicker response for sinusoidal voltage fluctuations at 120 V

Frequency Hz	Voltage fluctuations (%)	Frequency (Hz)	Voltage fluctuation (%)	Frequency (Hz)	Voltage fluctuation (%)
0.5	2.45694	6.5	0.36626	14	0.5297
1	1.46312	7	0.34555	15	0.59274
1.5	1.12419	7.5	0.33154	16	0.66247
2	0.94005	8	0.32294	17	0.73722
2.5	0.81391	8.8	0.32103	18	0.8147
3	0.71585	9.5	0.32954	19	0.89681
3.5	0.63609	10	0.33899	20	0.98109
4	0.56918	10.5	0.35451	21	1.07106
4.5	0.51372	11	0.37357	22	1.16351
5	0.46505	11.5	0.39432	23	1.26174
5.5	0.42578	12	0.41976	24	1.36529
6	0.39325	13	0.46958	25	1.47241

Table 4: Normal flicker response for rectangular voltage fluctuations at 120 V

Frequency Hz	Voltage fluctuation (%)	Frequency (Hz)	Voltage fluctuation (%)	Frequency (Hz)	Voltage fluctuation (%)
0.5	0.600	6.5	0.281	14	0.411
1	0.546	7	0.269	15	0.459
1.5	0.503	7.5	0.258	16	0.512
2	0.471	8	0.255	17	0.579
2.5	0.440	8.8	0.253	18	0.632
3	0.420	9.5	0.258	19	0.691
3.5	0.409	10	0.264	20	0.752
4	0.393	10.5	0.280	21	0.815
4.5	0.371	11	0.296	22	0.853
5	0.349	11.5	0.309	23	0.945
5.5	0.323	12	0.322	24	1.070
6	0.303	13	0.370		

4.2 Statistical analysis method

The P_{lt} recordings done every two hours for 7 consecutive days are used to perform the statistical calculations required to assess the weekly flicker level which is not exceeded 95% of the time. To do so, the weekly recordings are categorized in increasing order. Each value in the series is then linked to a percentile rank, from the smallest to the highest. The P_{lt} value which is found at the 95th percentile is compared to the target value of the voltage characteristic [1] and [5].

5.0 SHORT INTERRUPTIONS AND VOLTAGE DIPS

The measurement method and the classification of results used for short interruptions and voltage dips is described in section 5.6 of the CEA guide [2], except for the assessment of the rms voltage values, which should henceforth be done over one cycle rather than a half-cycle, as specified in references [1] and [5]. These differences will mainly affect the measurement results of disturbances lasting less than 1 cycle, which should therefore be interpreted accordingly.

6.0 TEMPORARY OVERVOLTAGES

The measurement method and classification of results used for temporary overvoltages is described in section 5.5 of the CEA guide [2], except for the assessment of the rms voltage values, which should henceforth be done over one cycle rather than a half-cycle, as specified in references [1] and [5]. These differences will mainly affect the measurement results of disturbances lasting less than 1 cycle, which should therefore be interpreted accordingly.

7.0 FREQUENCY VARIATIONS

The frequency measurement may be obtained using a digital frequency counter centred on the fundamental component of the supply voltage. Two analog filters must be used to reduce system disturbances which could affect measurement accuracy. The first, a second-order high-pass filter with a cut-off frequency of 51 Hz, allows a reduction of the supply voltage levels generated by subsynchronous phenomena. The second, a 6th order low-pass filter at the cut-off frequency of 69 Hz, ensures the filtering of system harmonics. Use of a Schmitt trigger circuit is recommended to make the frequency counter immune to the subharmonics and harmonics at 30 Hz and 120 Hz. The maximum error of the measuring device 99.99% of the time may not exceed 0.05 Hz. With a frequency counter, first the period of each cycle is measured then an average is obtained for each series of 12 consecutive cycles. Measurement of the 12-cycle period may also provide an excellent assessment of system frequency.

7.1 Statistical analysis method

The statistical method used to analyze frequency consists in counting the number of measurements exceeding the range described by the target values of frequency (N_f) and the weekly number of 12-cycle intervals (N_V) during which the supply voltage is within the normal operating range. The portion of time (*Fre*) during which the system frequency exceeds the range between the target values is obtained as follows:

$$Fre = \frac{N_V - N_f}{N_V} \times 100\% \qquad (7.1)$$

8.0 RAPID VOLTAGE CHANGES

Measurement of the rapid voltage changes is obtained by calculating the difference between the minimum and maximum rms voltage $ISV_{3\text{-}s}$ over a 3-s analysis period. Thus, to cover all possible 3-s intervals, the assessment is done for each step of 12-cycle window. Each voltage variation is expressed as a percentage of the average of the rms voltage levels recorded during the 9 s preceding the end of the 3-s analysis period.

The rms voltage $ISV_{3\text{-}s}$ over 3-s intervals can be measured using a “true rms” analog converter which provides a direct-current temporal signal that is proportional to the rms system voltage. The converter signal must be smoothed by a first-order RC filter with a 1.5-s time constant. The maximum $ISV_{max\ 3\text{-}s}$ values and minimum $ISV_{min\ 3\text{-}s}$ values at each 3-s interval of the signal smoothed by the filter must be recorded provided they do not exceed the range by ±10% of the nominal rms voltage V_d (rapid voltage change should not include voltage sags and short interruptions).

The voltage measured using a digital device, must meet the requirements specified in section 1.2. The instantaneous rms voltage ISV is obtained using equation 1.1 or 1.2. The device must calculate a single value for each 12-cycle period. Thus, a device which provides measurements over less than 12 cycles must incorporate gap to fill the difference between each window. For instance, if the device provides measurements over 8 cycles, a 4-cycle gap will have to be added between the measurements. If, on the other hand, the device provides measurements which exceed 12 cycles, an overlap with the previous window will be required to comply with the 12-cycle intervals per recording.

The rms value over 3 s is calculated in 12-cycle increments using the following equation with the ISV values from the previous 15 windows:

$$ISV_{3-s} = \sqrt{\frac{\sum_{i=-15}^{1} ISV_i^2}{15}} \qquad (8.1)$$

At each 3-s analysis period, the maximum value $ISV_{max\ 3\text{-}s}$ and the minimum value $ISV_{min\ 3\text{-}s}$ which are in the range that is ±10% within the nominal rms voltage V_d are recorded.

The ISV_i values obtained over each 9-s interval (up to 45 values) and found in the range that is within ±10% of the nominal rms voltage V_d used to determine the $ISV_{max\ 3\text{-}s}$ and $ISV_{min\ 3\text{-}s}$, are also used to calculate the average $ISV_{avg\ 9\text{-}s}$. Lastly, the values $ISV_{max\ 3\text{-}s}$, $ISV_{min\ 3\text{-}s}$ and $ISV_{avg\ 9\text{-}s}$. are used to calculate the rapid voltage change V_{rapid} using equation 8.2.

$$V_{rapid}(\%) = \frac{ISV_{\max 3-s} - ISV_{\min 3-s}}{ISV_{avg\ 9-s}} *100 \tag{8.2}$$

The V_{rapid} calculation must be done in 0.2-s (12-cycle) increments, with recordings of the previous 9 seconds.

9.0 TRANSIENT OVERVOLTAGES

Low-frequency and medium-frequency transient overvoltages (typically less than one-half cycle) are measured using specific methods depending on the type of phenomena involved. The measurement of transient overvoltages may require a special assembly and sensors to allow for precise measurement of high frequencies at high voltage levels. The assessment of transient overvoltages mainly involves measuring the voltage waveform and its instantaneous peak value with a device of an adequate bandwidth in relation to the frequency of the phenomena being considered.

10.0 ABBREVIATIONS USED IN THIS REPORT

IRO	Overvoltage in relation to the nominal rms voltage
IRU	Undervoltage in relation to the nominal rms voltage
ISV	Instantaneous rms voltage
IVH_1	Voltage amplitude at the fundamental frequency
IVH_n	Voltage amplitude at the frequency of harmonic order *n*
(N_V)	Number of 12-cycle intervals with a voltage level within the normal operating range
(N_f)	Number of 12-cycle intervals with a frequency out of the target value range
$U(t)$	Voltage sample measured at time *t*
$\vec{U}_{a-n}$	Voltage between phase “a” and the neutral
$\vec{U}_{b-n}$	Voltage between phase “b” and the neutral
$\vec{U}_{c-n}$	Voltage between phase “c” and the neutral
$\vec{U}_{a-b}$	Voltage between phase “a” and phase “b”
$\vec{U}_{b-c}$	Voltage between phase “b” and phase “c”
$\vec{U}_{c-a}$	Voltage between phase “c” and phase “a”
$U_{10min\text{-}over}$	Rms overvoltage level

$U_{10min\text{-}under}$	Rms undervoltage level
V_d	Nominal rms voltage (phase-to-neutral or phase-to-phase value, depending on the case)
V_{rapid}	Rapid voltage change
VUF_{2h}	Rms voltage unbalance level over a 2-h interval
P_{st}	Short-term flicker index
P_{lt}	Long-term flicker index

REFERENCES:

[1] – Characteristics and target values of the voltage supplied by Hydro-Québec transmission system, Études de réseau & Critères de Performance, D.P.D.A. TransÉnergie, translation July 5, 2001, original in French dated June 15, 1999.

[2] – CEA 220 D 711, Power quality measurement protocol, Roger Bergeron, Canadian Electricity Association, First Edition, March 1996.

[3] – IEC 61000-4-7 "Electromagnetic compatibility (ECM) – Part 4: Testing and measurement techniques – Section 7: General guide on harmonics and inter-harmonics measurements and instrumentation, for power supply systems and equipment connected thereto," IEC 1991.

[4] - IEC 61000-4-15 "Electromagnetic compatibility (ECM) – Part 4: Testing and measurement techniques – Section 15: Flickermeter – Functional and design specifications," IEC 1997.

[5] – Characteristic and target values of the voltage supplied by the Hydro-Québec medium and low voltage systems, Orientations de réseaux, Plans et stratégies d'Affaires, VP Distribution, translation June 2001, original in French dated June 2000.