POWER QUALITY BENCHMARK

Agriculture & Agri-Food Canada

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Morden, Manitoba
Premise # 6492969
Morden District

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APEGM
Certificate of Authorization
Manitoba Hydro
No. 38 Date: Oct 9, 2012

PROVINCE OF MANITOBA
Oct 9, 2012
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October 4, 2012

Manitoba Hydro
POWER SMART*

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1 SUMMARY

Based on the data collected, the power quality parameters are within Manitoba Hydro Power Quality Standards.

This Power Quality Benchmark provides an evaluation of electrical measurements made at Agriculture & Agri-Food Canada's at the Point of Common Coupling (PCC) with the Manitoba Hydro system from September 20, 2012 to September 27, 2012.

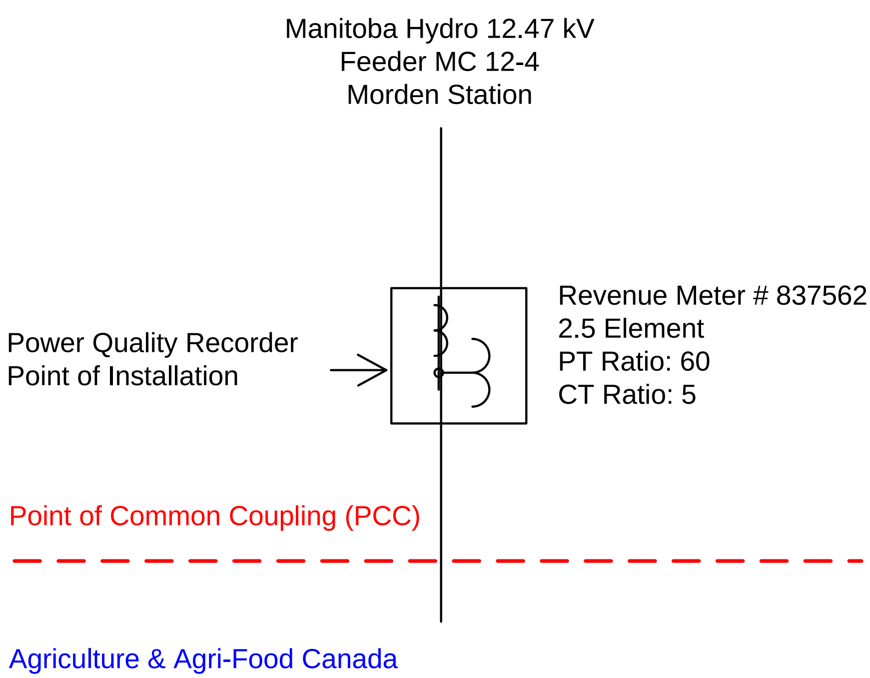
2 INTRODUCTION

The purpose of a Power Quality Benchmark is to ensure that both Manitoba Hydro's electrical supply and the customer's facility are operating within acceptable power quality limits at the Point of Common Coupling (PCC). The PCC is defined as the point on Manitoba Hydro's system that is electrically nearest to the customer's installation. For the purposes of this benchmark, the PCC is located at Agriculture & Agri-Food Canada's Revenue Meter # 837562.

A Power Quality Benchmark can be used as a diagnostic review of a facility's power quality at the PCC. Monitoring and benchmarking power quality characteristics can enhance a facility's predictive maintenance program by identifying power quality issues that can result in lost production, adverse interaction or equipment damage within the facility. In addition, a benchmark is a comparative tool that can be used to assess electrical system characteristics before and after large facility modifications.

To collect information for this benchmark a Dranetz PX5 Power Quality Recorder was installed at the PCC as shown in Figure 1. The electrical supply was monitored from September 20, 2012 at 11:15 to September 27, 2012 at 10:35. The analysis given in this report is valid only for the stated monitoring period.

Figure 1
Simplified Single Line Diagram



3 OBSERVATIONS

This section provides the relevant electrical operating limits as they apply to Agriculture & Agri-Food Canada - Morden. It also provides a graphical summary of the data collected at the PCC during the monitoring period from September 20, 2012 at 11:15 to September 27, 2012 at 10:35. In each subsection the measurement being evaluated, the applicable limit, and the measured values are stated. Note that the applicable limits are taken from Manitoba Hydro's Planning Criteria and Power Quality Specification PQS2000-01.

3.1 Voltage Variation

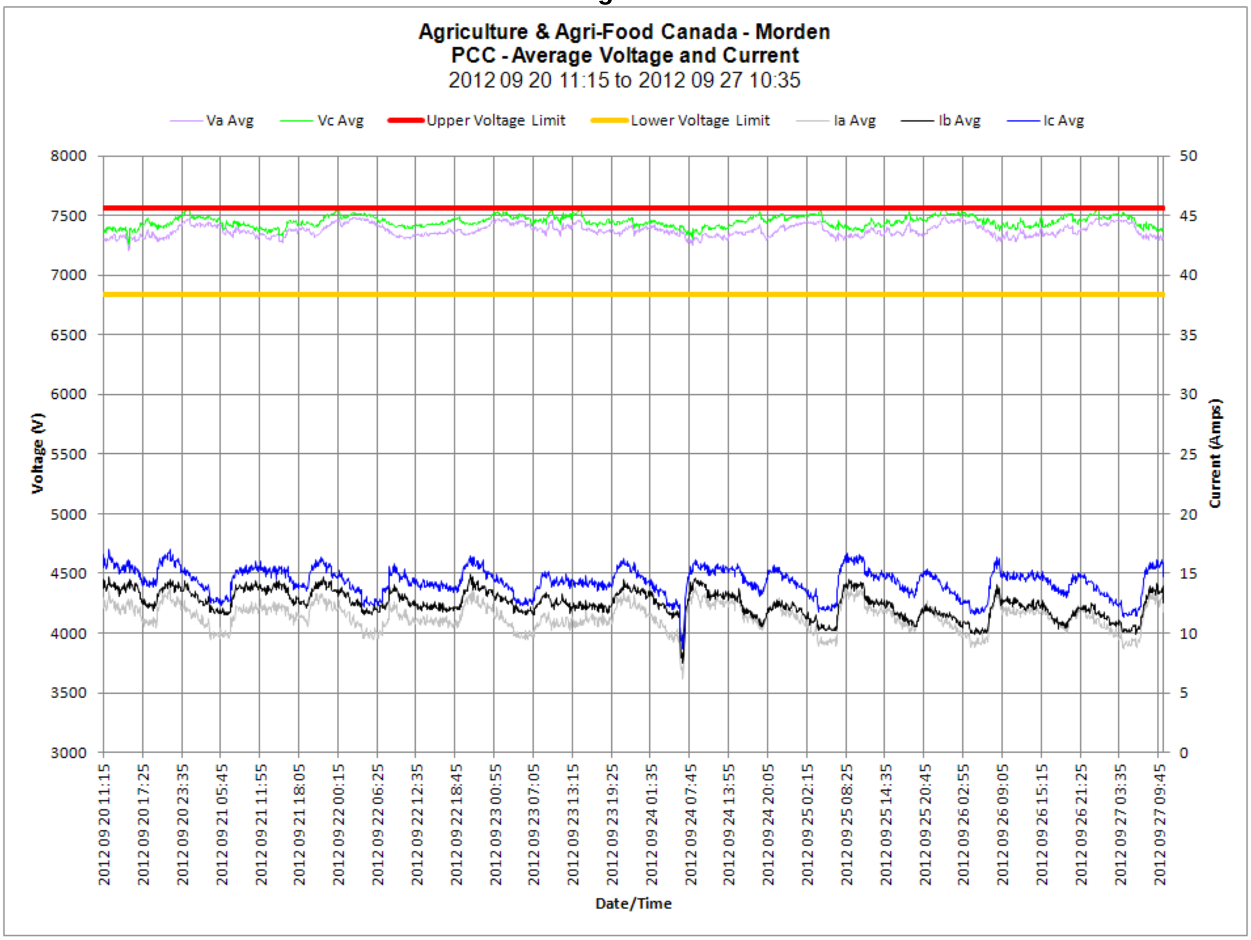
Average steady state voltage was found to be within acceptable limits 100% of the time during the monitoring period as required by Manitoba Hydro's Planning Criteria. The average steady state voltage range and upper and lower limits are provided in Table 1 below.

Table 1 - Voltage Variation Limits

Indices	Lower Limit	Measured Value	Upper Limit	Comments
Average Steady State Voltage Variation	6840 V	7207 V to 7567 V	7560 V	Within Manitoba Hydro's Planning Criteria

Figure 2 below shows the average steady state voltages and the upper and lower average steady state voltage limits. Figure also shows the average current values (in amps).

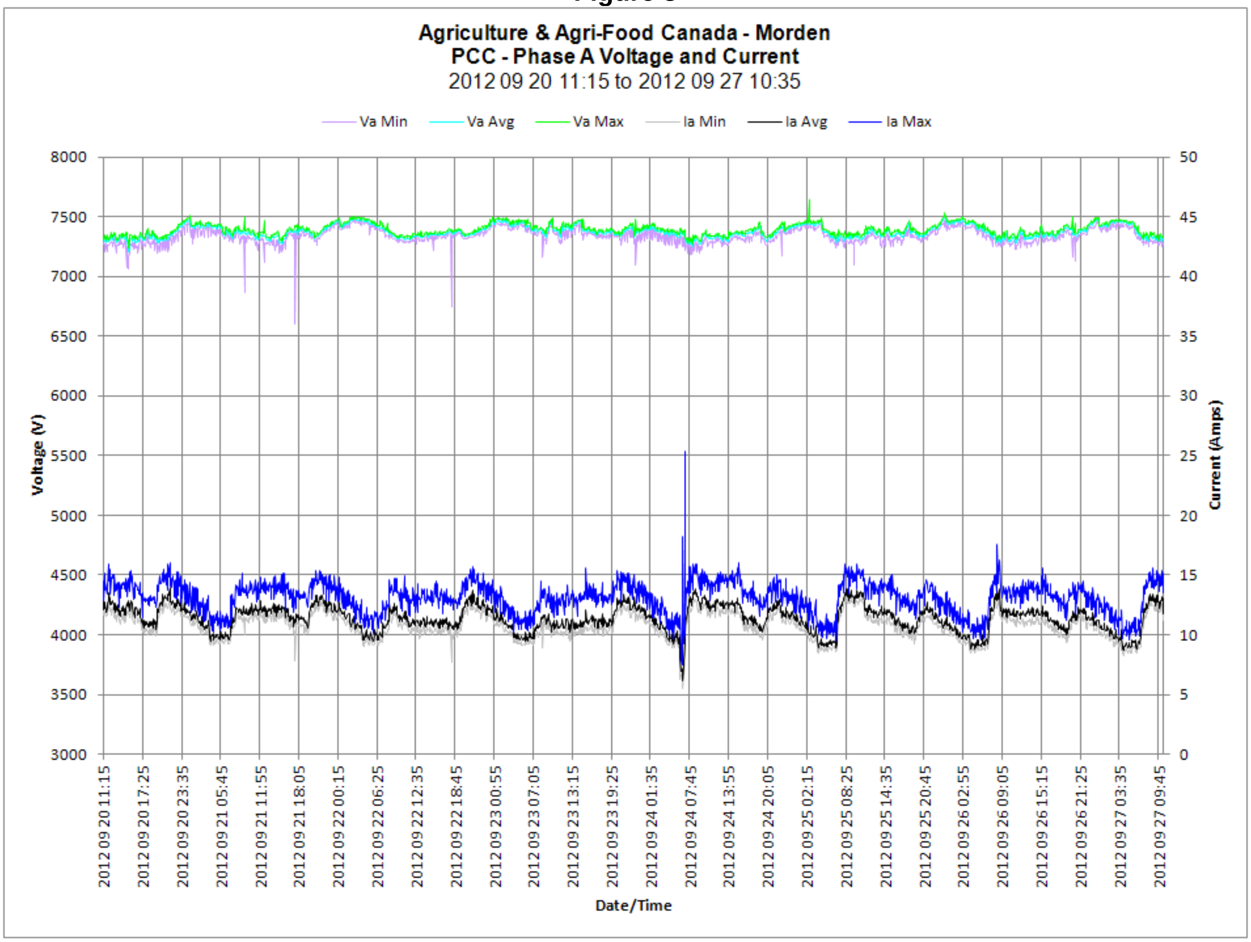
Figure 2



Average Voltage – A						**Average Voltage – C**		
Min	7207	15:15 Sep 20, 12				Min	7263	15:15 Sep 20, 12
Avg	**7375**					**Avg**	**7448**	
Max	7491	00:00 Sep 26, 12				Max	7567	00:40 Sep 21, 12
Average Current – A			**Average Current – B**			**Average Current – C**		
Min	6.2	06:45 Sep 24, 12	Min	7.5	06:45 Sep 24, 12	Min	8.7	06:45 Sep 24, 12
Avg	**11.4**		**Avg**	**12.5**		**Avg**	**14.3**	
Max	14.0	21:45 Sep 20, 12	Max	15.0	21:15 Sep 22, 12	Max	17.0	12:10 Sep 20, 12

Figure 3 below shows the minimum, maximum and average values for phase A voltage and phase A current. Graphs for phases B and C are available in Figure 4 and Figure 5 on pages 8 and 9 respectively.

Figure 3



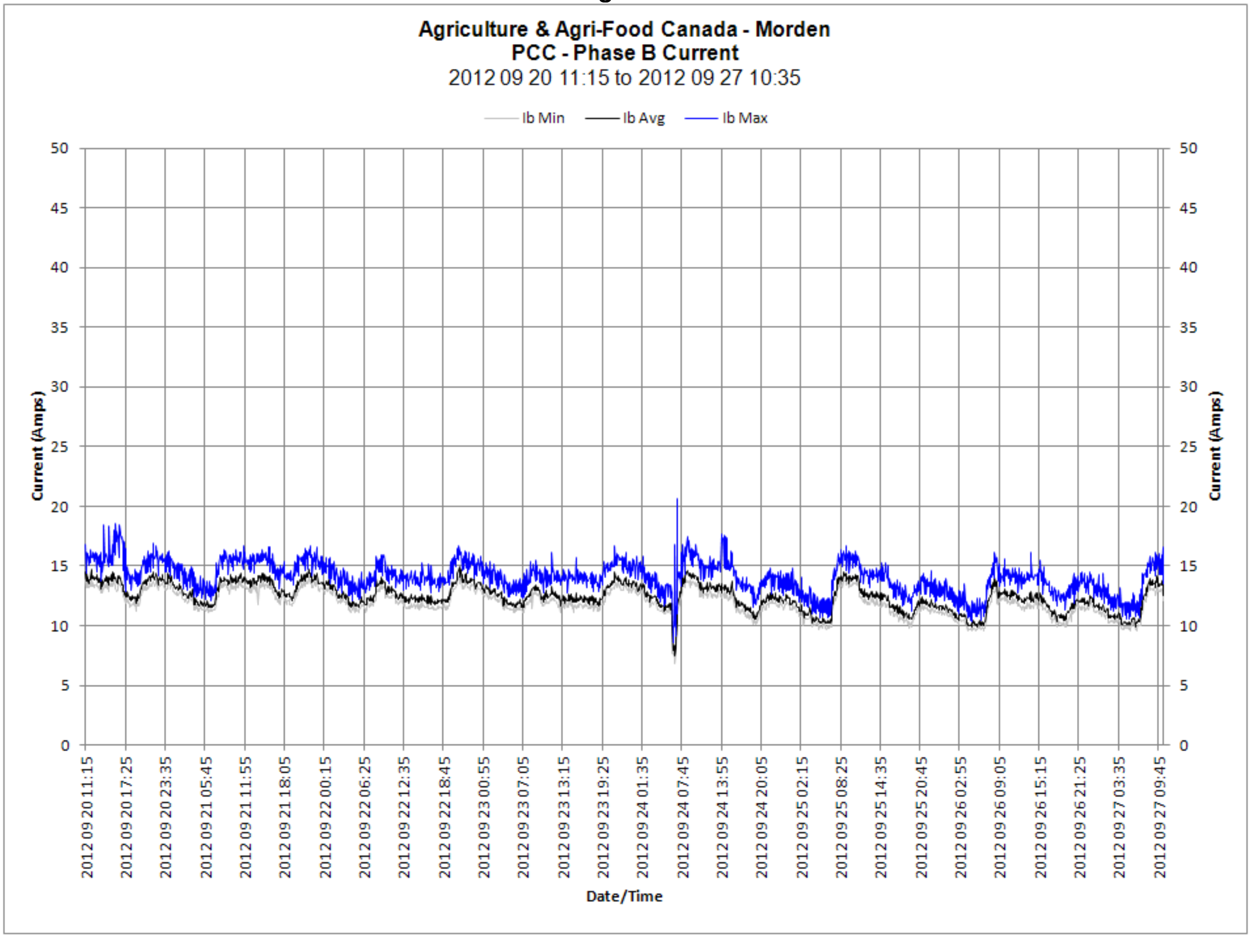
Voltage – A

Min	6603	17:30 Sep 21, 12
Avg	**7375**	
Max	7643	02:40 Sep 25, 12

Current – A

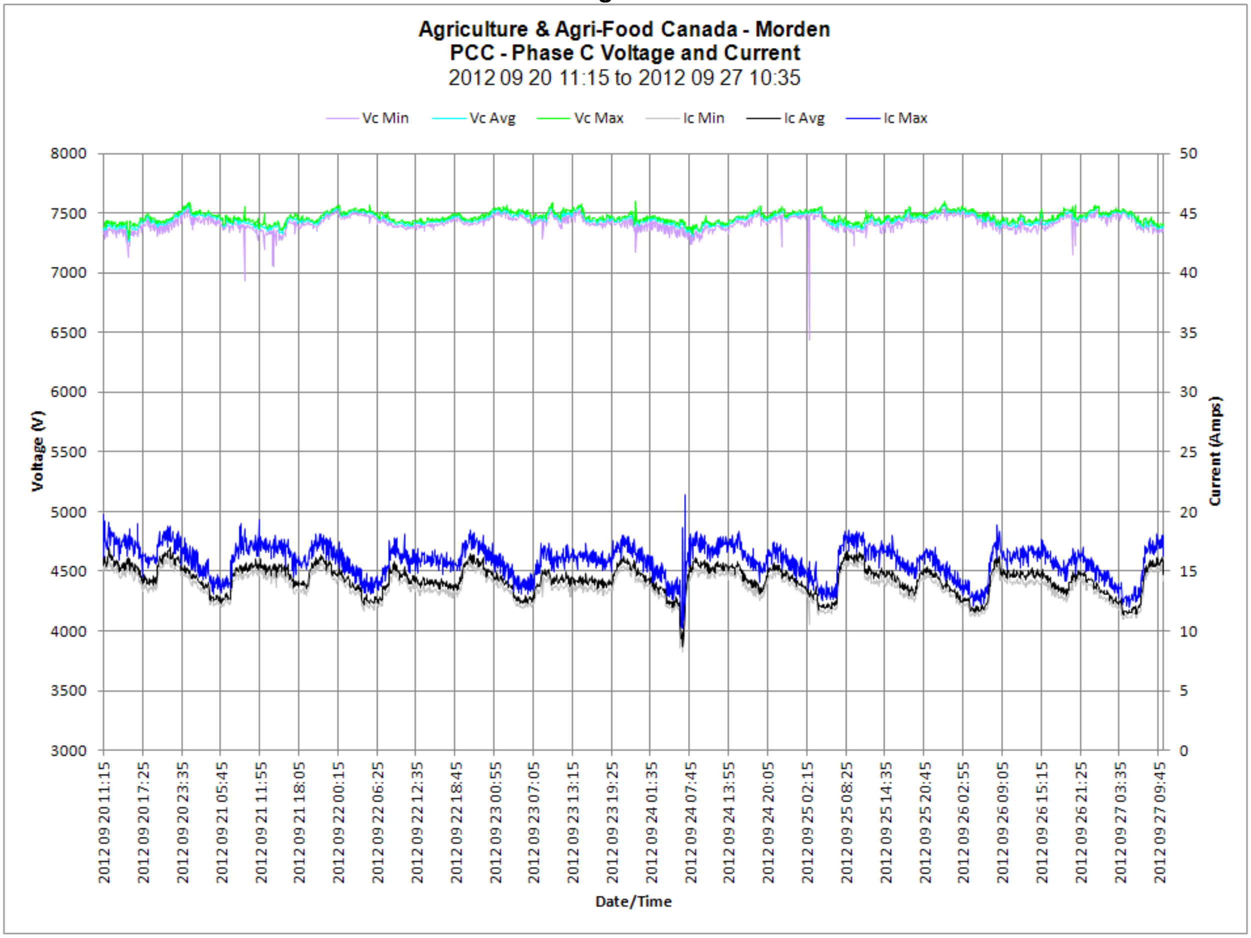
Min	5.5	06:40 Sep 24, 12
Avg	**11.4**	
Max	25.4	07:05 Sep 24, 12

Figure 4



Current – B		
Min	6.8	06:45 Sep 24, 12
Avg	**12.5**	
Max	20.7	07:00 Sep 24, 12

Figure 5



Voltage – C		
Min	6436	02:40 Sep 25, 12
Avg	**7448**	
Max	7603	00:00 Sep 26, 12
Current – C		
Min	8.2	06:40 Sep 24, 12
Avg	**14.3**	
Max	21.4	07:05 Sep 24, 12

3.2 Voltage Unbalance

Voltage unbalance was not evaluated as the monitoring information collected was from a 2 ½ element revenue metering system which only provides Phase A and C voltage, and three phase current information.

3.3 Voltage Harmonics

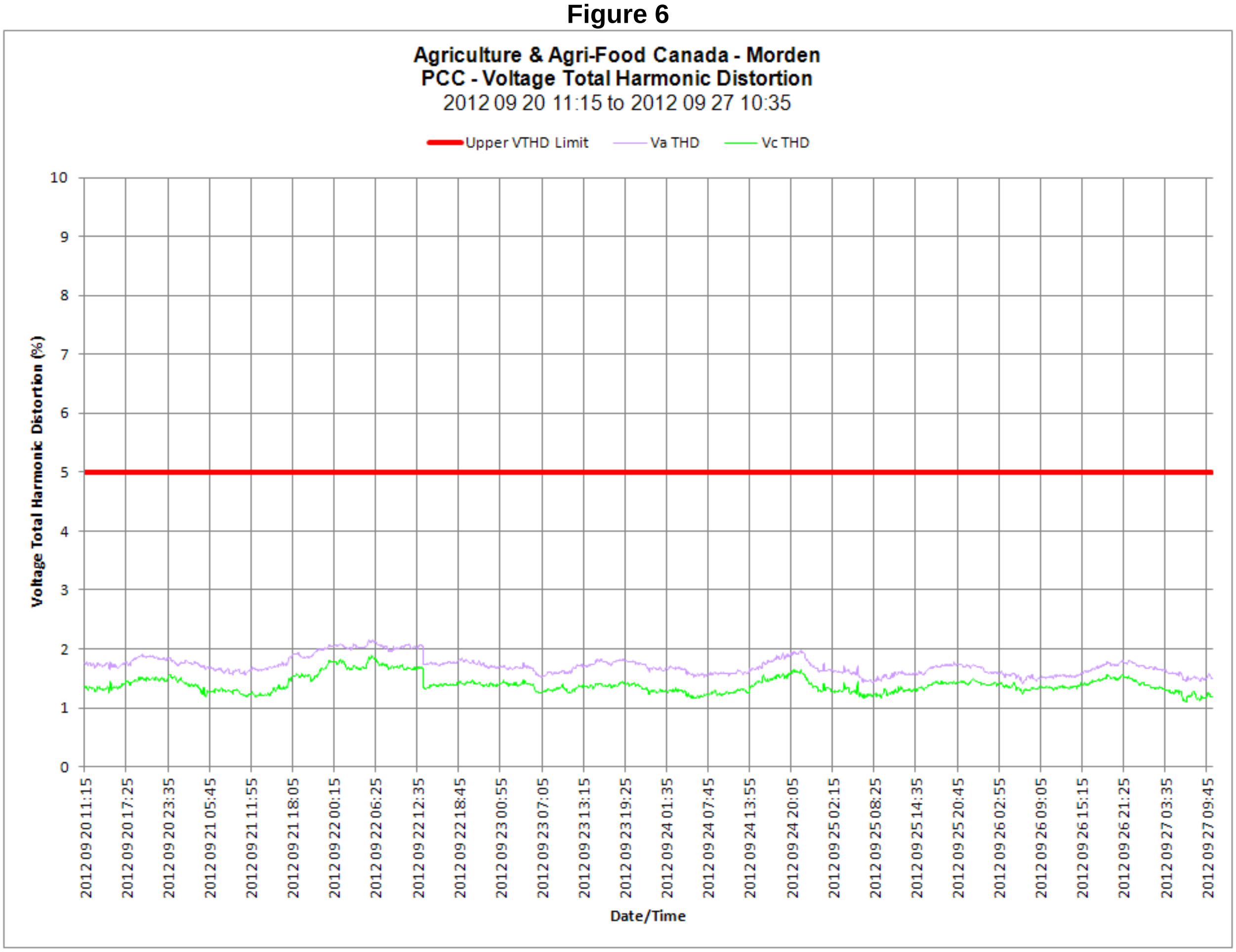
Voltage total harmonic distortion (THD) was within acceptable limits 100% of the time during the monitoring period as required by Manitoba Hydro's Power Quality Specification PQS2000-01. The average voltage THD and average voltage THD upper limit are provided in the Table 2 below.

Table 2 - Voltage Total Harmonic Distortion Limits

Indices	Measured Value	Upper Limit	Comments
Voltage Total Harmonic Distortion	2.2 %	5.0 %	Within PQS2000-01 Section 2.4.2 limit

Figure 6 below shows the average voltage THD and the upper voltage THD limit.

Figure 6



	Voltage THD – A			Voltage THD – C	
Min	1.4	06:30 Sep 26, 12	Min	1.1	06:35 Sep 27, 12
Avg	**1.7**		**Avg**	**1.4**	
Max	2.2	05:25 Sep 22, 12	Max	1.9	05:55 Sep 22, 12

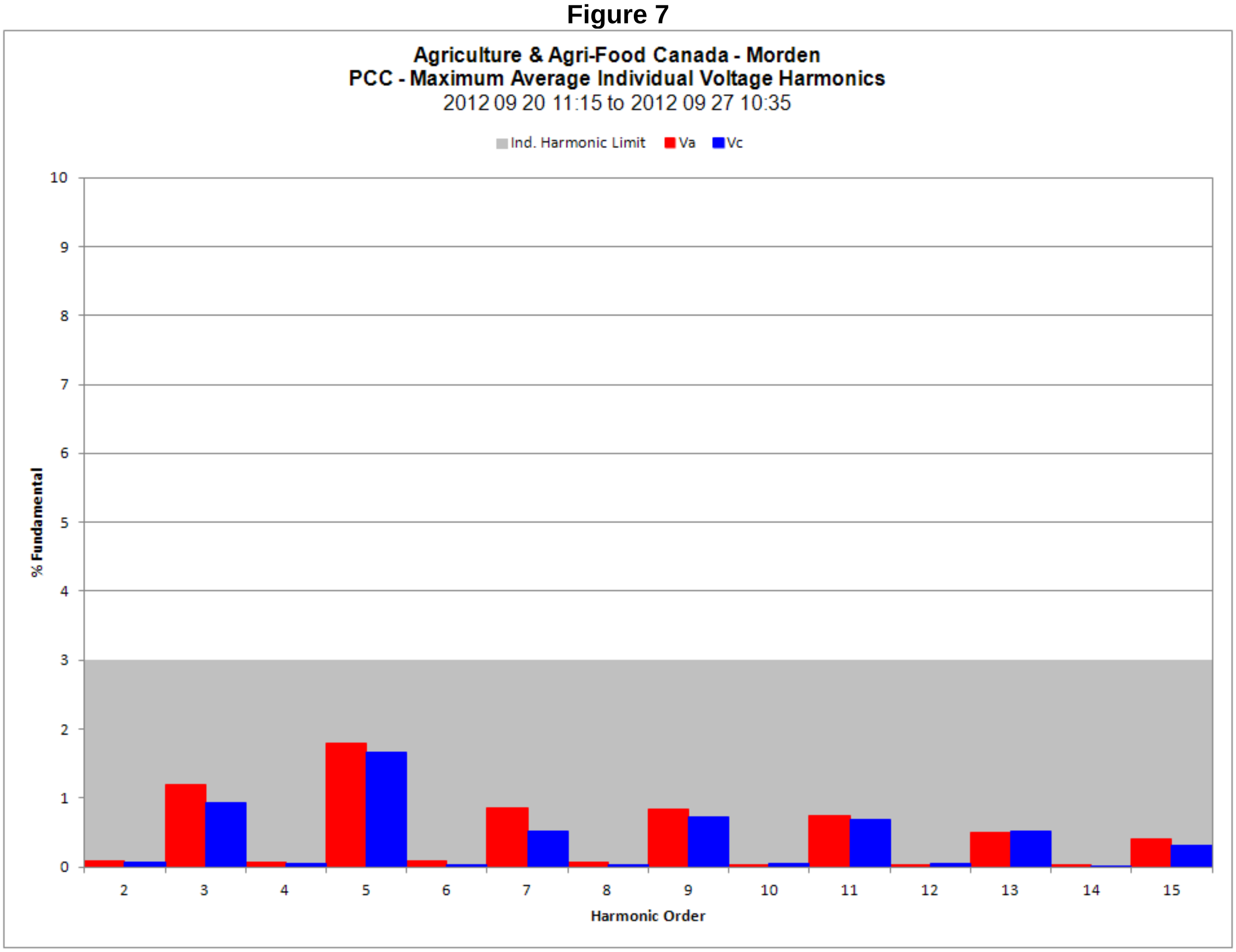
Individual maximum average voltage harmonics were within acceptable limits 100% of the time during the monitoring period as required by Manitoba Hydro's Power Quality Specification PQS2000-01. The individual voltage harmonics and applicable limit are provided in Table 3 below.

Table 3 - Maximum Average Individual Voltage Harmonic Limits

Phase	Harmonic Range	Largest Harmonic	Magnitude (% Fundamental)	Upper Limit	Comments
A	h≥2	5	1.8 %	3.0 %	Within PQS2000-01 Section 2.4.2 limit
C	h≥2	5	1.7 %	3.0 %	Within PQS2000-01 Section 2.4.2 limit

Figure 7 below shows the individual maximum average voltage harmonics and individual maximum average voltage harmonic limit.

Figure 7



3.4 Current Harmonics

Current total demand distortion (TDD) was within acceptable limits at least 95% of the time during the monitoring period as required by Manitoba Hydro's Power Quality Specification PQS2000-01. Note that the limit for current TDD is determined based on the ratio of symmetrical short circuit level at the PCC to Agriculture & Agri-Food Canada's peak demand current (I_L) in the previous 12 month period. The peak demand current and the symmetrical short circuit level are given below for Agriculture & Agri-Food Canada at 12.47 kV:

Short Circuit level at the PCC *	1938	A	I_{SC}
Agriculture & Agri-Food Canada Peak Load October 2011	24	A	I_L
I_{SC}/I_L =	**81**		

* NOTE: The identified fault current (I_{SC}) is not to be used for equipment sizing, harmonic mitigation or arc flash calculations. It is only to be used to establish current total demand distortion limits.

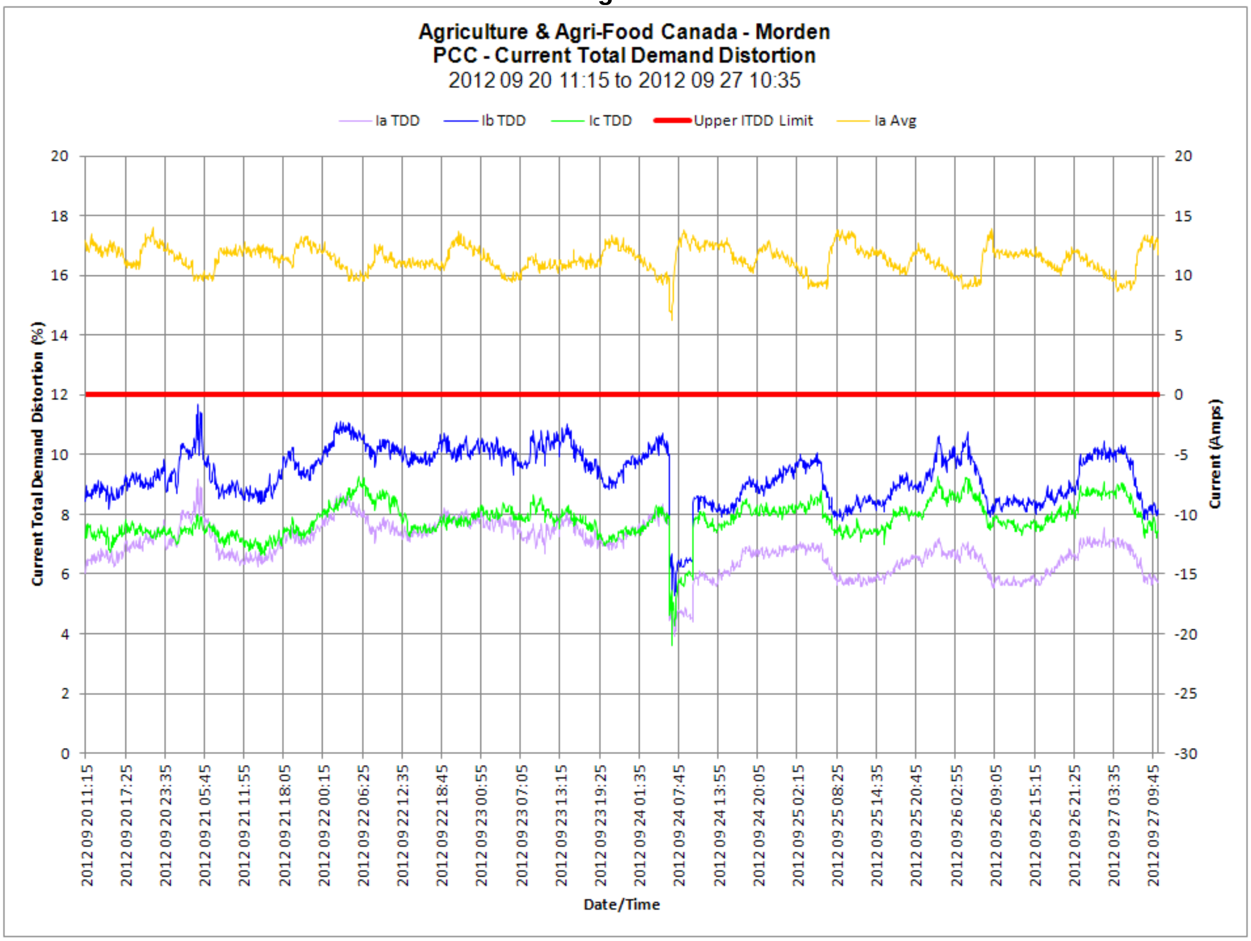
The current TDD and applicable limit based on the ratio of I_{SC} to I_L are provided in Table 4 below. Note that Agriculture & Agri-Food Canada - Morden should operate their facility such that their TDD remains below the limit specified at least 95% of the time.

Table 4 - Current Total Demand Distortion Limits

Indices	Measured Value	Upper Limit	Comments
Current Total Demand Distortion	10.6 %	12.0 %	Within PQS2000-01 Section 2.4.3 limit

Figure 8 on page 14 shows the average current TDD and upper current TDD limit.

Figure 8



	Current TDD – A			Current TDD – B			Current TDD – C	
Min	3.9	07:05 Sep 24, 12	Min	5.3	07:05 Sep 24, 12	Min	3.6	06:45 Sep 24, 12
Avg	**6.9**		**Avg**	**9.3**		**Avg**	**7.8**	
Max	9.2	04:50 Sep 21, 12	Max	11.7	04:50 Sep 21, 12	Max	9.3	05:50 Sep 22, 12
95%	8.0*		95%	10.6*		95%	8.8*	

*Measurements were less than or equal to value for 95% of the monitoring period.

Individual current harmonics were within acceptable limits at least 95% of the time during the monitoring period as required by Manitoba Hydro's Power Quality Specification PQS2000-01. The individual current harmonics and limits for each range of harmonics are provided in Table 5 below.

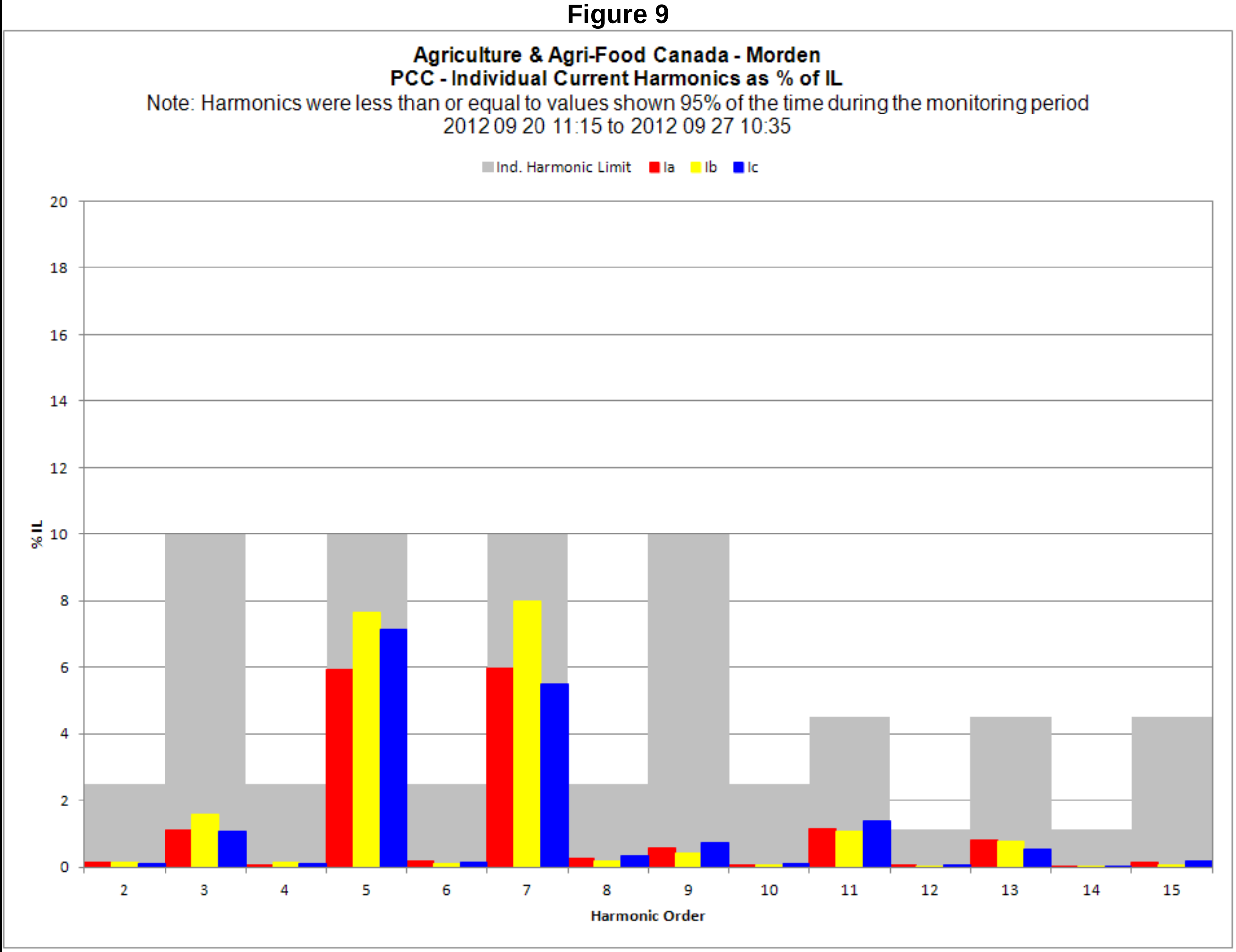
Table 5 - Individual Current Harmonic Limits

Phase	Harmonic Range	Largest Harmonic	Magnitude (% I_L)	Upper Limit*	Comments
A	h<11 11≤h<17	7 11	6.0 % 1.1 %	10 % 4.5 %	Within PQS2000-01 Section 2.4.3 limit
B	h<11 11≤h<17	7 11	8.0 % 1.1 %	10 % 4.5 %	Within PQS2000-01 Section 2.4.3 limit
C	h<11 11≤h<17	5 11	7.1 % 1.4 %	10 % 4.5 %	Within PQS2000-01 Section 2.4.3 limit

*Note that the limit for even harmonics is 25% that of the limit for odd harmonics.

Figure 9 below shows the individual current harmonics and the upper individual current harmonic limits.

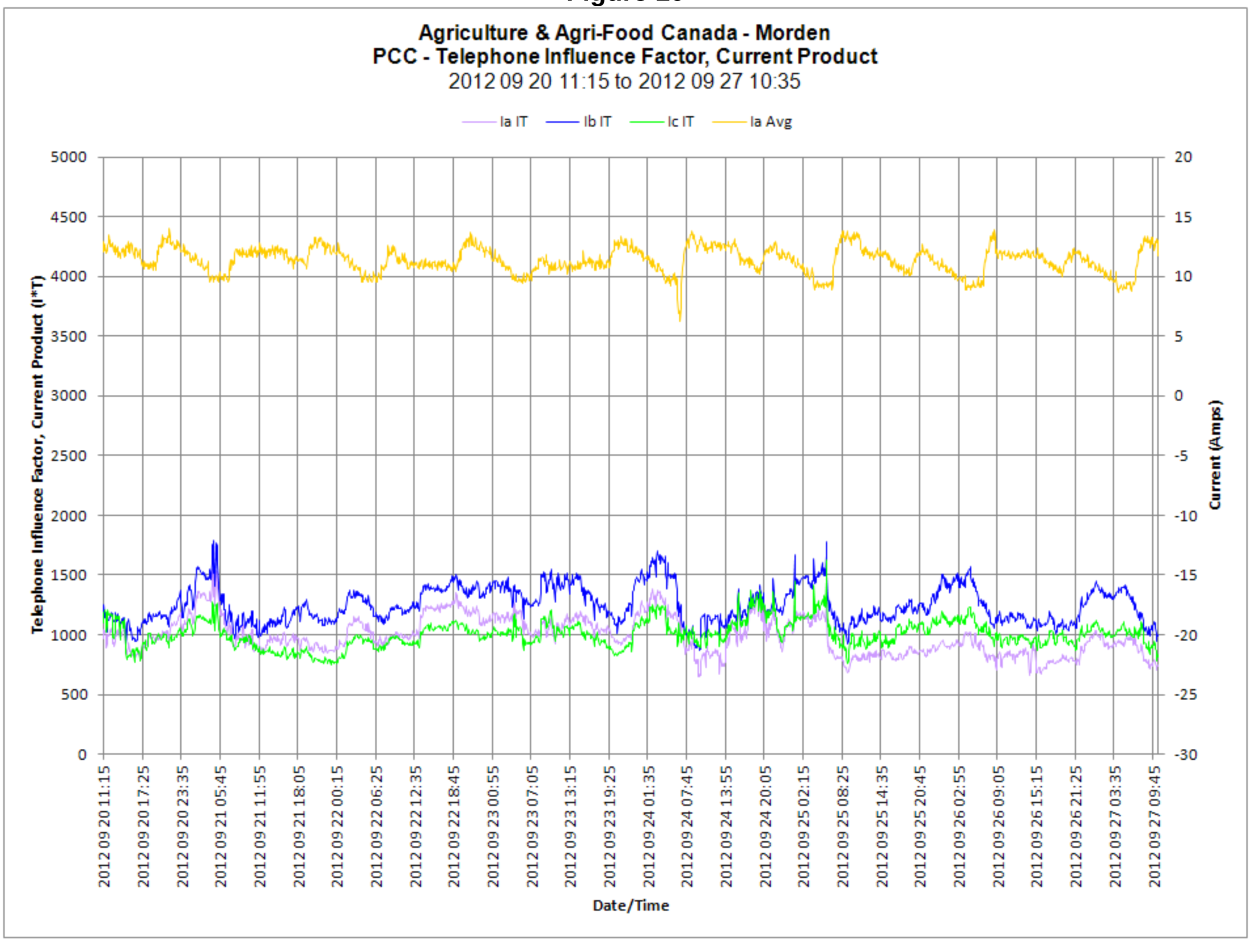
Figure 9



3.5 Communication Interference

Figure 10 below shows the Telephone Influence Factor, Current Product (I·T) levels recorded during the monitoring period. The I·T levels have been included for reference purposes.

Figure 10



Telephone Influence Factor, Current Product – A

Min	645	09:40 Sep 24, 12
Avg	**994**	
Max	1569	04:50 Sep 21, 12

Telephone Influence Factor, Current Product – B

Min	870	09:50 Sep 24, 12
Avg	**1252**	
Max	1789	04:50 Sep 21, 12

Telephone Influence Factor, Current Product – C

Min	750	23:25 Sep 21, 12
Avg	**1006**	
Max	1622	06:00 Sep 25, 12

3.6 Voltage Flicker

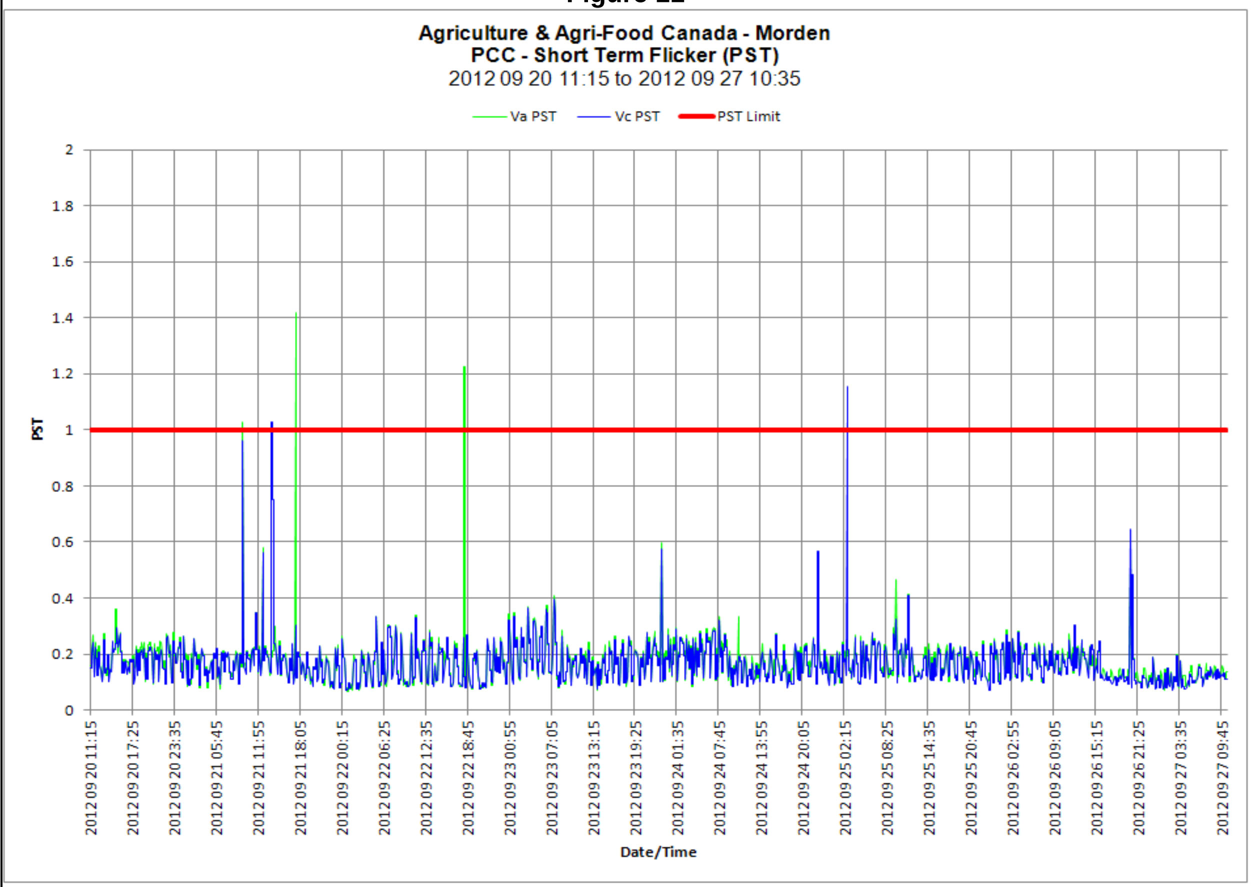
Short Term Flicker (PST) and Long Term Flicker (PLT) were found to be within acceptable limits at least 99% of the time during the monitoring period as required by Manitoba Hydro's Power Quality Specification PQS2000-01. The PST and PLT and their limits are provided in Table 6 below.

Table 6 - Voltage Flicker Limits

Indices	Measured Value	Upper Limit	Comments
Short Term Flicker (PST) - 99th Percentile	0.41	1.0	Within PQS2000-01 Section 3.3.1 limit
Long Term Flicker (PLT) - 99th Percentile	0.62	0.8	Within PQS2000-01 Section 3.3.1 limit

Figure 11 below shows the PST and its upper limit. Figure 12 on page 18 shows the PLT and its upper limit.

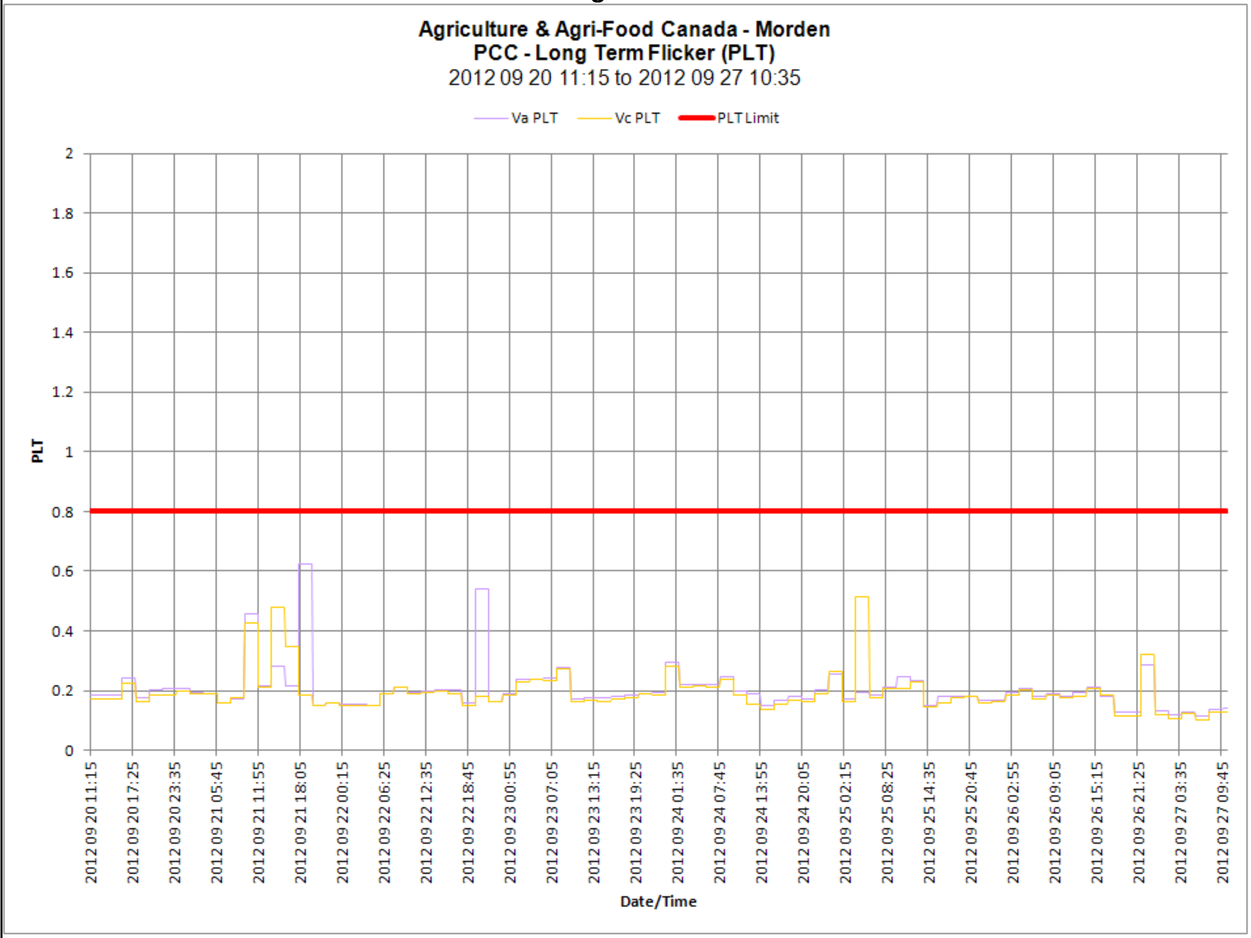
Figure 11



PST – A			PST – C		
Min	0.07	01:10 Sep 22, 12	Min	0.07	02:30 Sep 27, 12
Avg	**0.17**		**Avg**	**0.17**	
Max	1.42	17:30 Sep 21, 12	Max	1.16	02:40 Sep 25, 12
99%	0.41*		99%	0.39*	

*Measurements were less than or equal to value for 99% of the monitoring period.

Figure 12



PLT – A			PLT – C		
Min	0.11	06:00 Sep 27, 12	Min	0.10	06:00 Sep 27, 12
Avg	**0.20**		**Avg**	**0.19**	
Max	0.62	17:40 Sep 21, 12	Max	0.51	04:00 Sep 25, 12
99%	0.62*		99%	0.51*	

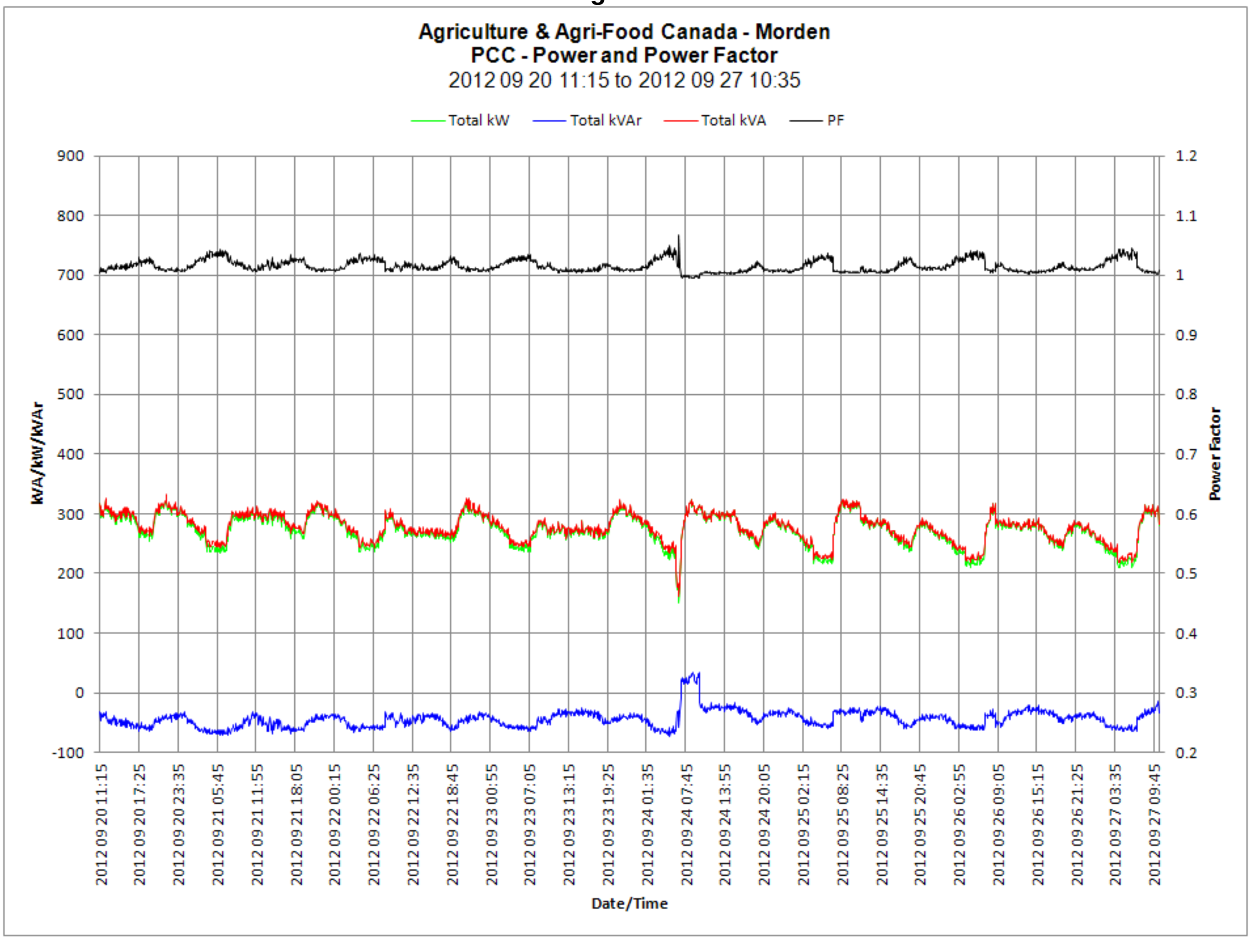
*Measurements were less than or equal to value for 99% of the monitoring period.

4 POWER AND POWER FACTOR

The peak demand recorded during the monitoring period was 332 kVA with a leading power factor of 1.01. This peak occurred on September 20, 2012 at 21:45. The highest peak demand recorded in the last 12 month period at was 522 kVA recorded in October 2011.

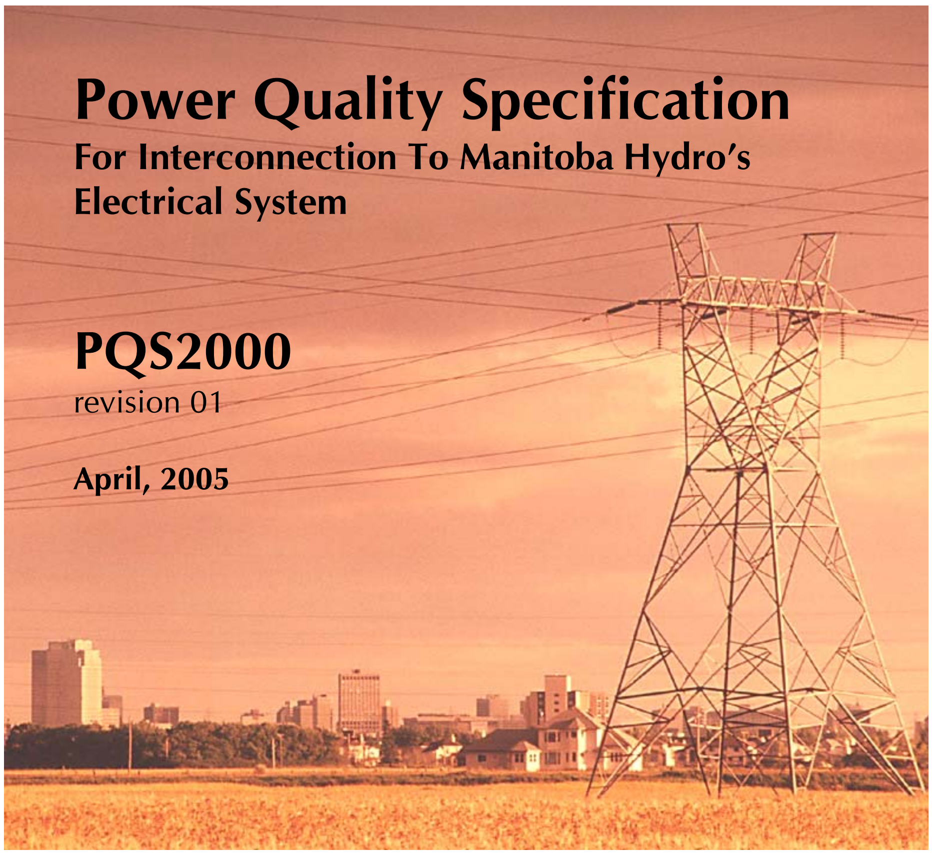
Figure 13 below shows the power data recorded during the monitoring period. This data is not evaluated against any limit, but is provided for Agriculture & Agri-Food Canada's interest.

Figure 13



Total kW				**Total kVAr**		
Min	151	06:45 Sep 24, 12		Min	-72.6	05:15 Sep 24, 12
Avg	**274**			**Avg**	**-43.9**	
Max	330	21:45 Sep 20, 12		Max	34.8	08:55 Sep 24, 12
Total kVA				**Power Factor**		
Min	161	06:45 Sep 24, 12		Min	0.99	08:55 Sep 24, 12
Avg	**278**			**Avg**	**1.02**	
Max	332	21:45 Sep 20, 12		Max	1.07	06:45 Sep 24, 12
Monitoring Period Peak Demand						
Peak Demand	332	September 20, 2012 at 21:45		PF	1.01	

Appendix A



Power Quality Specification

For Interconnection To Manitoba Hydro's Electrical System

PQS2000

revision 01

April, 2005

Manitoba Hydro
POWER SMART

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1.0 General Information

1.1 Legislative Authority

Section 15(5) of The Manitoba Hydro Act authorizes Manitoba Hydro to set, coordinate and enforce standards for the security, reliability and quality control of the transmission and distribution lines, of any person whose lines are interconnected with the transmission and distribution lines of Manitoba Hydro. Pursuant to section 10 of Regulation 186/90 – Electric Power Terms and Conditions of Supply, Manitoba Hydro is authorized to determine the voltage, frequency, phasing and other characteristics of power, the determination of which is final and binding on the user. Pursuant to this legislative authority, Manitoba Hydro has established the following Power Quality Specification.

1.2 Authors

The primary authors of this document are:

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It was written in collaboration with, and is maintained by, the Manitoba Hydro Power Quality Committee which includes representation from the following departments:

Service Quality
Business Engineering Services Department
System Planning Department
System Performance Department
Electrical Distribution Planning & Design Department

1.3 Revisions

Revision Date	Major Changes
01 – January 2005	▪ added Flicker criteria ▪ revised harmonic burst criteria ▪ revised the section related to mitigation responsibilities ▪ created a General Information section
00 – November 2000	Document created, addressed harmonics only

note:

Manitoba Hydro will review this document periodically and make revisions necessary to reflect changing system conditions and industry practices. When revisions are made, Manitoba Hydro will distribute the revised document to all regular recipients as soon as practically possible and make copies available upon request, however, it is the customer's responsibility to ensure it has the latest version of this document.

1.4 Mitigation Of Power Quality Problems

When Limits Are Exceeded:

It is Manitoba Hydro intent to plan and design its system so power quality levels are within the limits specified in this document.

In emergency situations, it may be necessary for Manitoba Hydro to make temporary changes to its system which may adversely affect power quality levels. Under these circumstances, distortion and/or flicker levels at the PCC may be temporarily exceeded.

The Manitoba Hydro service contract deals with concerns when limits are exceeded and covers responsibilities for mitigation of power quality interference issues.

Manitoba Hydro may perform a post installation Power Quality analysis for comparison with the original benchmark. If power quality limits are exceeded, Manitoba Hydro will assist the customer in determining the cause of the problem only.

1.5 Definitions

The following definitions are specific to Manitoba Hydro and may differ from those used by IEEE and other Industry Standards:

Flicker: flicker is the impact a voltage fluctuation has on the luminous intensity of lamps and fluorescent tubes such that they are perceived to 'flicker' when viewed by the human eye. The level at which it becomes irritating is a function of both the magnitude of the voltage change and how often it occurs.

Flicker is quantified using the following:

Pst: the short-term flicker index, a unit of flicker level as defined in IEC Standard 61000-4-15 based on a 10 minute period. P_{st} is obtained by direct measurement using the IEC "flicker meter", calculated analytically, or obtained through computer simulation. In North America, a P_{st} of 1.0 (one) corresponds to the 'threshold of flicker irritation' for rectangular (step) voltage changes applied to a 120V incandescent lamp.

Plt: the long-term flicker index. P_{lt} is calculated using 12 consecutive (120 minutes) P_{st} samples and is given by:

$$P_{lt} = \sqrt[3]{\frac{1}{12} \cdot \sum_{j=1}^{12} P_{st_j}{}^{3}}$$

Emission Level: the maximum allowable P_{st} contribution available to a customer connecting a load assuming there is zero background flicker.

Planning Level: this is the maximum P_{st} and P_{lt} level used by the utility for planning purposes and is used to control the cumulative impact of all fluctuating loads connected to the system.

Flicker Curve: a graph that plots voltage fluctuations vs. frequency of occurrence. The points on the curve are based on laboratory experiments that applied a periodic voltage fluctuation to a light bulb and determined the levels at which the flicker becomes irritating to the human eye. Most published flicker curves are based on rectangular modulation of the 60 Hz AC voltage waveform.

Flicker meter: an instrument used to measure the severity of flicker and determine the level in terms of P_{st} and P_{lt}. The specifications for a flicker meter are outlined in IEC Standard 61000-4-15.

Point Of Common Coupling (PCC): the location on the Manitoba Hydro system electrically nearest to the customer installation. It is where access for Power Quality measurement is obtained and other customers are, or can be, connected. It can be located on either the primary or secondary side of a supply transformer depending on whether multiple customers are supplied from the transformer.

Power Quality Assessment and Mitigation Report: a technical report supplied to Manitoba Hydro by the customer which includes the following:

- detailed description of equipment being installed including all nameplate data, single-line diagrams, etc.
- projected impact new equipment will have on harmonic and flicker levels
- projected levels of interference with communication circuits
- description of measures that will be taken to mitigate harmonic levels exceeding the limits specified in this document
- description of measures that will be taken to mitigate flicker levels exceeding the limits specified in this document
- calculations and/or computer simulation that verifies corrective measures will work

Power Quality Benchmark: measurements taken at the PCC which include voltage and current levels, voltage and current total harmonic distortion trending, power usage and power factor. Usually performed before new non-linear loads are installed in order to establish baseline characteristics of the system and allow for future comparisons.

Total Harmonic Distortion (THD): total harmonic distortion is defined as:

$$THD = \frac{\sqrt{\sum_{h=2}^{50} V_h^2}}{V_1} \times 100\%$$

where:

V_h	=	magnitude of individual harmonic components at frequency '*h*'
h	=	harmonic frequency (of 60Hz) which can be integer or non-integer (interharmonic)
V_1	=	the magnitude of the nominal fundamental frequency voltage

Total Demand Distortion (TDD): total demand distortion is defined as:

$$TDD = \frac{\sqrt{\sum_{h=2}^{50} I_h^2}}{I_L} \times 100\%$$

where:

Ih	=	magnitude of individual harmonic components
h	=	harmonic frequency of (60Hz) which can be integer or non-integer (interharmonic)
I_L	=	maximum annual demand load current (fundamental frequency component) at PCC

Voltage Variation: a change in the magnitude of the RMS voltage level. Voltage variations are generally of three types:

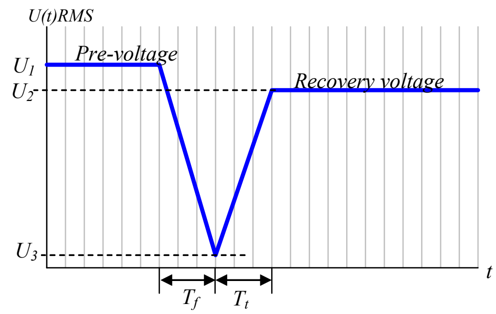
i) **Voltage Sag**: a voltage variation in which the magnitude of the RMS voltage drops to a level below nominal, then returns to nominal. The voltage magnitude is typically between 0.1 and 0.9 *per-unit* (PU), and lasts anywhere from 0.5 cycles to 1 minute. A variation that is under 0.5 cycles is called a *'transient'*, and anything over 1 minute is considered an *'under voltage'*.

ii) **Voltage Swell**: a voltage variation in which the magnitude of the RMS voltage increases to a level above nominal, then returns to nominal. The voltage magnitude is typically between 1.1 and 1.8 PU, and lasts anywhere from 0.5 cycles to 1 minute.

iii) **Voltage Fluctuation**: a series of voltage changes or a continuous variation on the RMS voltage magnitude. Fluctuations are typically small voltage variations, (but not necessarily), ranging anywhere between 0.9 and 1.1 PU in magnitude.

Voltage fluctuations can be one of two types:

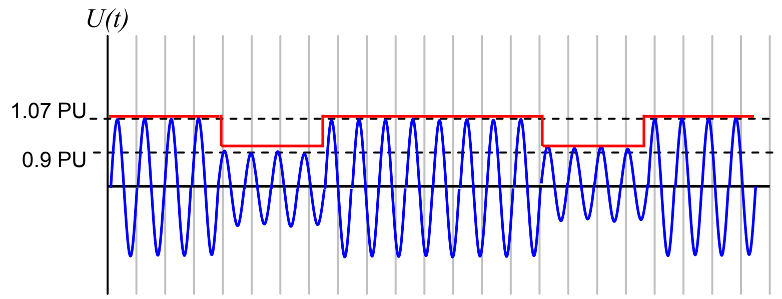
Dynamic (aperiodic) Fluctuations are caused by the starting and stopping of large inductive loads. Starting a motor or energizing a transformer are good examples. The RMS voltage drops, then recovers to a steady-state level that is less than the pre-voltage. One dynamic fluctuation produces 2 voltage changes.



T_f = front time
T_t = tail time

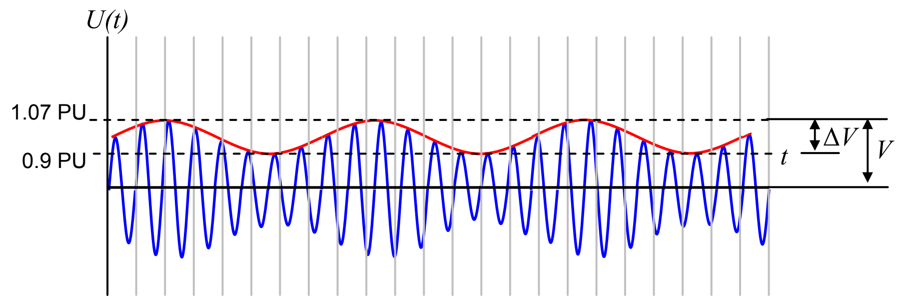
Cyclic (periodic) Fluctuations are part of the normal, continuous operation of the load. The RMS voltage magnitude varies between two values resulting in amplitude modulation of the AC sine wave envelope.

Periodic voltage fluctuation that results in rectangular modulation of the 60 Hz waveform.
e.g.: wood running through a sawmill

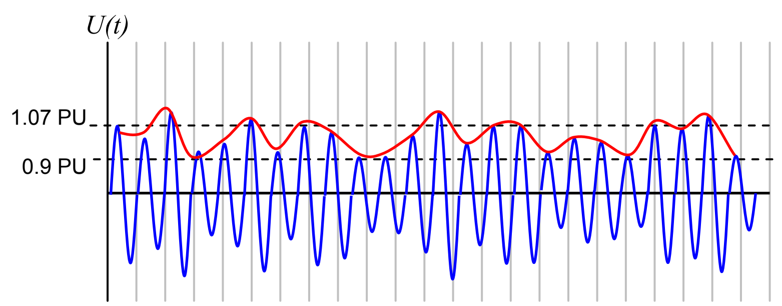


Periodic voltage fluctuation that results in sinusoidal modulation of the 60 Hz waveform. The %voltage fluctuation is calculated using:

$$\frac{\Delta V}{V} \cdot 100$$



Periodic voltage fluctuation that results in random modulation of the 60 Hz waveform.
e.g.: arc furnace during its melting cycle



2.0 Waveform Distortion

2.1 Introduction

If a load draws a sinusoidal current when it is connected to a sinusoidal voltage supply, it is called a ‘linear’ load. When the load draws a non-sinusoidal (distorted) current, the load is called ‘non-linear’. When non-linear currents are allowed to flow through the linear elements in a utility electrical system, the resulting voltage drops are non-sinusoidal. If allowed to accumulate, they can degrade the quality of the utility supply voltage. One way to control utility voltage quality is to limit the amount of waveform distortion produced by individual non-linear loads.

2.1.1 Purpose

The purpose of this section is to establish responsibilities and to specify limits for harmonic and interharmonic distortion created by non-linear loads connecting to the Manitoba Hydro electrical system.

2.2 General Requirements

It is Manitoba Hydro’s responsibility to provide and maintain a voltage supply within harmonic limits as specified in this document. Based on engineering information provided by Manitoba Hydro, it is the customer’s responsibility to ensure its load does not increase harmonic levels on the Manitoba Hydro system beyond limits specified herein and does not impact other customers' electrical services. This section describes, in detail, the flow of information between Manitoba Hydro and the customer.

2.2.1 Customers Affected By This Document

All new or existing customers whose load may exceed acceptable harmonic levels or who may be affecting nearby customers are impacted by this document. This is typical of:

- customers adding large non-linear loads to the Manitoba Hydro system
- customers who have or who are considering installing power factor correction capacitors

2.2.2 Information Supplied By The Customer

Whenever customers propose connecting equipment (as defined in 2.2.1) to the Manitoba Hydro system, or whenever existing customers may be exceeding harmonic limits, Manitoba Hydro requires all relevant information pertaining to the connected loads, including:

i) single-line diagram of the installation
ii) all non-harmonic producing loads
iii) all harmonic producing loads and their harmonic spectrums
iv) transformer ratings and impedance
v) cable impedance that should be included for harmonic analysis
vi) power factor correction capacitor and filter information, if applicable

note: For 66kV and greater interconnections, refer to Manitoba Hydro’s “Transmission System Interconnection Requirements” document for more details regarding other information that may be required.

2.2.3 Basis For a Power Quality Benchmark

Upon reviewing the information supplied in 2.2.2, Manitoba Hydro, at its discretion, will perform a Power Quality Benchmark measurement at the PCC. The basis for doing so will be determined using existing data and by the extent to which the Manitoba Hydro system will be impacted.

Whenever a Power Quality Benchmark measurement is performed, the following information will be supplied to the customer[1]:

system data:

i) normal short circuit MVA level at the PCC
ii) supply transformer nameplate information (when applicable)
iii) impedance spectrum at the PCC (when applicable)

measured data:

iv) voltage and current levels
v) total harmonic distortion, (voltage and current), at the PCC
vi) power usage and power factor

1 Where a technical representative is acting on behalf of the customer, this information will be provided to the customer only, unless the customer has provided written consent for Manitoba Hydro to provide the information to such representative.

2.2.4 Power Quality Assessment and Mitigation Report

Upon receiving the Power Quality Benchmark information, the customer must provide Manitoba Hydro with a Power Quality Assessment and Mitigation Report. This report must include information outlined in Section 2.2.2 and demonstrate that the harmonic limits specified in section 2.4 are met. Service connection will not be granted until the report is received and reviewed by Manitoba Hydro.

2.3 Harmonic Measurement

Harmonics and interharmonics up to the 50^{th} shall be included in all calculations.

2.3.1 Measurement Period

When performing a Power Quality Benchmark, Manitoba Hydro shall normally perform measurements at the customer PCC for one week (168 hour period) during typical production load levels. The effect of a shorter production cycle and seasonal variation of loads will be considered in determining when a benchmark is performed. Manitoba Hydro reserves the right to choose the date/time and duration of the benchmark measurements.

2.3.2 Analysis Period

The maximum allowable level of total demand distortion (TDD) is determined with reference to the customer's I_{SC}/I_L ratio and Table 2.4.3 of this document. Actual TDD is based on data obtained during the measurement period. All customer facilities are expected to be at or below the maximum allowable TDD 95% of the time during all normal operating cycles. For shorter periods, during start ups or other transient conditions, the limits may be exceeded by up to 50% (1.5x the design limit). The TDD must be less than 1.5x the design limit 99% of the time during all normal operating cycles, with no occurances exceeding 2.0x the design limit.

2.3.3 Equipment

Power harmonic analyzers must be capable of performing power quality measurements and harmonic calculations from n=1 to 50. They shall have a minimum sampling rate of 128 samples/cycle, (8kHz), with a resolution of at least once every 15 minutes.

2.4 Limits For Design Purposes

The criteria in this section shall be applied to design studies and equipment specifications.

2.4.1 Voltage Unbalance

The customer's design shall account for unbalance in the voltage supply using Table 2.4.1, where unbalance is defined as the ratio of negative sequence voltage to positive sequence voltage, or alternatively,

$$\%unbalance = \frac{Highest\ deviation\ from\ the\ average\ voltage\ of\ the\ 3\ phases}{Average\ voltage\ of\ the\ 3\ phases}$$

Table 2.4.1 - Voltage Unbalance Limits

Voltage Level	**Rural**	**Urban**
25kV and less	5.0%	4.0%
greater than 25kV	2.0%	

2.4.2 System Voltage Distortion

Manitoba Hydro shall normally limit the voltage distortion levels at the PCC to a maximum of the following values:

Table 2.4.2 - Maximum System Voltage Distortion @PCC

Bus Voltage at PCC (V_{bus})	**Individual harmonic or interharmonic voltage distortion (%)**	**Total Voltage Distortion THD (%)**
69kV and less	3.0	5.0
$138kV \geq V_{bus} > 69kV$	1.5	2.5
$V_{bus} > 138kV$	1.0	1.5

These values represent distortion levels based on the cumulative effect of all customers connected to the same point on the supply.

2.4.3 Customer Current Distortion

As part of the Harmonic Assessment and Mitigation Report, the customer shall demonstrate that current distortion limits at the PCC will not exceed the limits as specified in this document. The values are summarized in Table 2.4.3.

Table 2.4.3 – Current Distortion Limits
Maximum Harmonic Current Distortion In Percent of I_{Load}
Individual Harmonic Order (Odd Harmonics)

			$V_{bus} \leq 69kV$			
I_{sc}/I_L	<11	$11 \leq h<17$	$17 \leq h<23$	$23 \leq h<35$	$35 \leq h$	TDD
<20*	4.0	2.0	1.5	0.6	0.3	**5.0**
20 - 49	7.0	3.5	2.5	1.0	0.5	**8.0**
50 - 99	10.0	4.5	4.0	1.5	0.7	**12.0**
100 - 1000	12.0	5.5	5.0	2.0	1.0	**15.0**
>1000	15.0	7.0	6.0	2.5	1.4	**20.0**
			$69kV < V_{bus} \leq 138kV$			
I_{sc}/I_L	<11	$11 \leq h<17$	$17 \leq h<23$	$23 \leq h<35$	$35 \leq h$	TDD
<20*	2.0	1.0	0.75	0.3	0.15	**2.5**
20 - 49	3.5	1.75	1.25	0.5	0.25	**4.0**
50 - 99	5.0	2.25	2.0	0.75	0.35	**6.0**
100 -1000	6.0	2.75	2.5	1.0	0.5	**7.5**
>1000	7.5	3.5	3.0	1.25	0.7	**10.0**
			$V_{bus} > 138kV$			
I_{sc}/I_L	<11	$11 \leq h<17$	$17 \leq h<23$	$23 \leq h<35$	$35 \leq h$	TDD
<50*	2.0	1.0	0.75	0.3	0.15	**2.5**
≥50	3.0	1.5	1.15	0.45	0.22	**3.75**

- Harmonics and interharmonics up to h = 50 shall be included in all design calculations
- Even harmonics are limited to 25% of the odd harmonics listed above
- Current distortions that result in a DC offset, e.g., half-wave converters, are not allowed
- Duration of harmonic levels is outlined in section 2.3.2

*All power generation equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L or voltage level

where:

I_{SC} = short-circuit current for normal system conditions that result in minimum short circuit capacity at the PCC, considering all supply alternatives

I_L = maximum annual demand load current (fundamental frequency component) at PCC

2.4.4 Customer Voltage Distortion

The customer shall design its installation and specify equipment such that the steady state voltage distortion (VTHD) contribution due to the installation complies with Table 2.4.4 below.

Table 2.4.4 - Maximum Customer Voltage Distortion Design Limits

Bus Voltage at PCC (V_{bus})	Individual harmonic or interharmonic voltage distortion (%)	Total Voltage Distortion THD (%)
69kV and less	2.0	3.5
138kV $\geq V_{bus}$ > 69kV	1.0	1.5
V_{bus} > 138kV	1.0	1.0

Table 2.4.4 ensures that total bus voltage distortion levels do not exceed levels specified in Table 2.4.2 particularly in the case of parallel resonance.

2.4.5 System Frequency

Calculations and design shall consider a fundamental frequency range of:

Table 2.4.5 – Frequency

Continuous	60 ± 0.2 Hz
≤ 30 seconds	58 Hz to 63.5 Hz

2.5 Limits of Interference With Communication Circuits

2.5.1 Power Line Interference on Telephone Lines

Communication circuits most susceptible to power line interference are low frequency, analog telephone circuits. The interference is a function of separation between the power circuit and the telephone line, the parallel distance, and the plant susceptibility and interference potential of the power line.

The interference potential of the power line can be estimated using the I·T product described by;

$$I \cdot T = I_{RMS} \times TIF$$

however, the complexity of the problem makes it extremely difficult to accurately calculate the interference level with all 3 factors included. As a result, this guideline relies on measurements to check compliance.

2.5.2 Design Limits

The maximum balanced and residual Inductive Influence (I·T) levels shall be as follows:

Table 2.5.1 – Maximum I*T Limits @PCC	
Balanced I·T	**Residual I ·T**
6000	100

Power line influenced noise can be measured at the telephone plant. Using special instruments, "noise to ground" can be measured in dBrnc, (decibel C-message weighted). Measurements of noise to ground (Ng) $\leq$ 80 dBnrc will generally not cause telephone interference.

2.5.3 Communication Interference

Manitoba Hydro strives to keep the balanced I·T product harmonic interference level below 6000 on any one line that may cause induction into communication circuits. For any particular application, Manitoba Hydro is prepared, if necessary, to discuss the allowable I·T as specified in section 2.5 with the understanding that any required interference mitigation directly resulting is the responsibility of the customer.

After it has demonstrated that its plant meets minimum standards for integrity and susceptibility, the communication company, with Manitoba Hydro's cooperation, is responsible for demonstrating the violation of telephone interference limits and identifying (when applicable) the customer suspected of causing interference problems.

3.0 Flicker

3.1 Introduction

Electrical equipment that is switched or switches as part of its normal operation, may cause voltage fluctuations. From a utility's perspective, there are 2 issues that raise concern:

- the risk of the voltage magnitude being outside accepted tolerances
- 'flicker' effect from light sources as a result of the fluctuation

Section 3.0 explains the flicker requirements of loads connecting to the Manitoba Hydro system.

3.1.1 Manitoba Hydro's Flicker Philosophy

Manitoba Hydro plans and designs its system primarily;

- to meet steady-state load demand (KVA) requirements
- to ensure steady-state voltage levels are within CSA Standards
- to maintain reliability levels that are as good or better than industry averages

For economic reasons, Manitoba Hydro does not plan or design its network to carry the starting current requirements of individual loads. As a result, voltage fluctuations introduced by these loads may cause visible flicker depending on the size of the load, the impedance of the system at that point, and the frequency of the fluctuations.

Manitoba Hydro's responsibility is to ensure that overall flicker levels are kept within acceptable levels by placing limits on voltage fluctuations introduced at the customer's point of common coupling. Based on engineering information provided by Manitoba Hydro, it is the customer's responsibility to ensure its load does not introduce voltage fluctuations beyond limits specified in this document.

3.1.2 Purpose

Section 3.0 establishes a uniform practice pertaining to voltage fluctuations and their impact on the Manitoba Hydro electrical system and other customers. This creates equity among customers in different parts of the Province, clarifies responsibilities of both the customer and Manitoba Hydro, and protects the overall integrity of the Manitoba Hydro system.

3.1.3 Scope

Section 3.0 establishes responsibilities for and specifies limits of voltage fluctuations introduced at the point of common coupling between the Manitoba Hydro electrical system and its customers. It covers the following voltage ranges:

HV System	> 25 kV
MV System	1000 V - 25 kV
LV System	<1000 V

This is a technical document and does not address other policy or contractual requirements associated with interconnection to the Manitoba Hydro system.

3.2 General Information

3.2.1 Customers Affected By This Section

All new or existing customers whose load introduces voltage fluctuations, or who may be affecting nearby customers are impacted by this document. This is typical of:

- customers adding large non-linear loads to the Manitoba Hydro system
- customers who have or who are considering installing large motors (typically 15hp or greater for 3 phase, and 5hp or greater for 1 phase)

3.2.2 Information Supplied By The Customer

Whenever customers propose connecting equipment (as defined in section 3.2.1) to the Manitoba Hydro system, or whenever existing customers are introducing voltage fluctuations that cause other customers to complain, Manitoba Hydro requires all relevant information pertaining to the connected load(s).

General information is documented in the Electric Service Application form. Additional information specific to flicker producing loads includes;

- the load starting request form
- maximum %voltage fluctuation and expected rate of fluctuation during steady state operation

3.2.3 Information Supplied To The Customer

For motors and other large loads, Manitoba Hydro will provide load starting calculations and starting restriction(s).

In the case of load that produce periodic fluctuations during steady state operation, Manitoba Hydro shall provide;

- a background flicker measurement
- the short circuit MVA at the PCC

3.2.4 Power Quality Assessment and Mitigation Report

After the exchange of information, the customer shall provide Manitoba Hydro with a Power Quality Assessment and Mitigation Report that includes the expected flicker emission levels of the new load.

Manitoba Hydro, at its discretion, may perform a post installation flicker measurement to ensure that planning levels have not been exceeded by the addition of the new load(s). The results of the measurement shall be provided to the customer. They can also be provided to a consultant working on behalf of the customer, if the customer provides written consent for Manitoba Hydro to provide the results to such consultant.

3.3 Limits For Controlling Flicker Levels

Manitoba Hydro strives to maintain a cumulative background flicker (planning) level of $\mathbf{P_{ST} < 1.0}$ and $\mathbf{P_{LT} < 0.8}$, 99% of the time**,** throughout its system. To achieve this, flicker emission limits have been established for individual loads connecting at various PCC voltages.

3.3.1 Limits For Flicker Levels

The customer shall design its equipment such that its flicker emission levels do not exceed the limits in table 3.3.1. The calculations shall assume there is no background flicker.

Table 3.3.1 – Customer Emission Limits[1]

PCC Voltage	P_{ST}	P_{LT}
LV (<1000 V)	1.0	0.8
MV (1000 V – 25 kV)	0.9	0.7
HV (>25 kV)	0.8	0.6

[1] at or below these limits, 99% of the time, based on a 7 day benchmark measurement or other representative load cycle 1 day or greater

3.3.2 Limits For Voltage Fluctuations

This section contains limits for voltage fluctuations introduced by individual loads. By establishing limits on individual voltage fluctuations, Manitoba Hydro can ensure customers meet the emission limits in table 3.3.1.

3.3.2.1 Automatic Acceptance

Generally speaking, if the rate of voltage fluctuation is known, the first step in evaluating the disturbance level of a new load is to relate the maximum apparent power (S_{max}) of the load to the short-circuit power (S_{sc}) available at the PCC:

$$\Delta V\% = \frac{S_{\max}}{S_{sc}} \cdot 100$$

- S_{max} should include the maximum power seen during starting
- for induction motors, S_{max} is typically 6X to 8X rated horsepower
- for induction furnaces, S_{max} is typically 2X to 4X rated KVA

Table 3.3.2 – Limits For Relative Power Variations[1]

Changes per minute	ΔV
< 10	0.4%
10 to 200	0.2%
> 200	0.1%

[1] Taken from IEC 1000-3-7 Table 4

Loads having *%ΔV* values at or below the levels specified in Table 3.3.2 are considered acceptable and **further flicker analysis is not required**. For values above the limits, sections 3.3.2.2 and 3.3.2.3 apply.

3.3.2.2 Limits For Dynamic Fluctuations

Dynamic voltage fluctuations are usually caused by the starting and stopping of motors. However, energization of other loads including transformers and capacitors may also cause brief voltage fluctuations. The primary reason for limiting dynamic fluctuations is to ensure proper operation of the load itself. The second reason is flicker. Although a single motor alone may not generate flicker complaints, the cumulative effect of several motors starting randomly on a distribution feeder can.

Using the information supplied by the customer in section 3.2.2, Manitoba Hydro first determines the ability of the system to supply the energy necessary to start and operate the proposed load(s). Using computer simulation of the supply circuit, the cumulative %voltage drop is calculated from the station to the customer PCC.

Based on the results of the simulation, Manitoba Hydro limits starting and operation of the load(s) to the values shown in table 3.3.3.

Table 3.3.3 - Load Starting Restrictions

Voltage Change @PCC	Restriction
<2.0%	no restriction
2.0 – 2.4%	twice per hour
2.5 – 2.9%	once per hour
3.0 – 3.4%	once every 2 hours
3.5 – 3.9%	once every 4 hours
4.0 – 4.9%	once per day
5.0 – 7.0%	not allowed[5]
>7%	not allowed[5]

Notes:

1. In some applications, a motor may cause voltage fluctuations during its steady state operation (jogging, jamming) and starting restrictions alone may not be sufficient. For these situations, section 3.3.2.3 applies.
2. For induction motors, Manitoba Hydro assumes a 6X locked rotor current.
3. Computer simulation is used to determine the maximum voltage fluctuation.
4. The table assumes **one start produces 2 voltage changes**.
5. Will be reviewed on a 'case by case' basis, and may be allowed in certain situations, (eg. a once-per-year transformer energization)

3.3.2.3 Limits For Periodic Fluctuations

When voltage fluctuations are produced by the normal, steady-state operation of a load (or loads), they are called 'periodic fluctuations'. Periodic fluctuations usually (but not necessarily) occur at frequencies greater than 1.0 changes/minute. Loads displaying this characteristic are typical of, but not limited to:

- arc furnaces
- welders
- motor jogging
- saw mills

Manitoba Hydro requires that individual loads do not introduce periodic fluctuations, at their PCC, above the curves shown in figure 3.3.1 below.

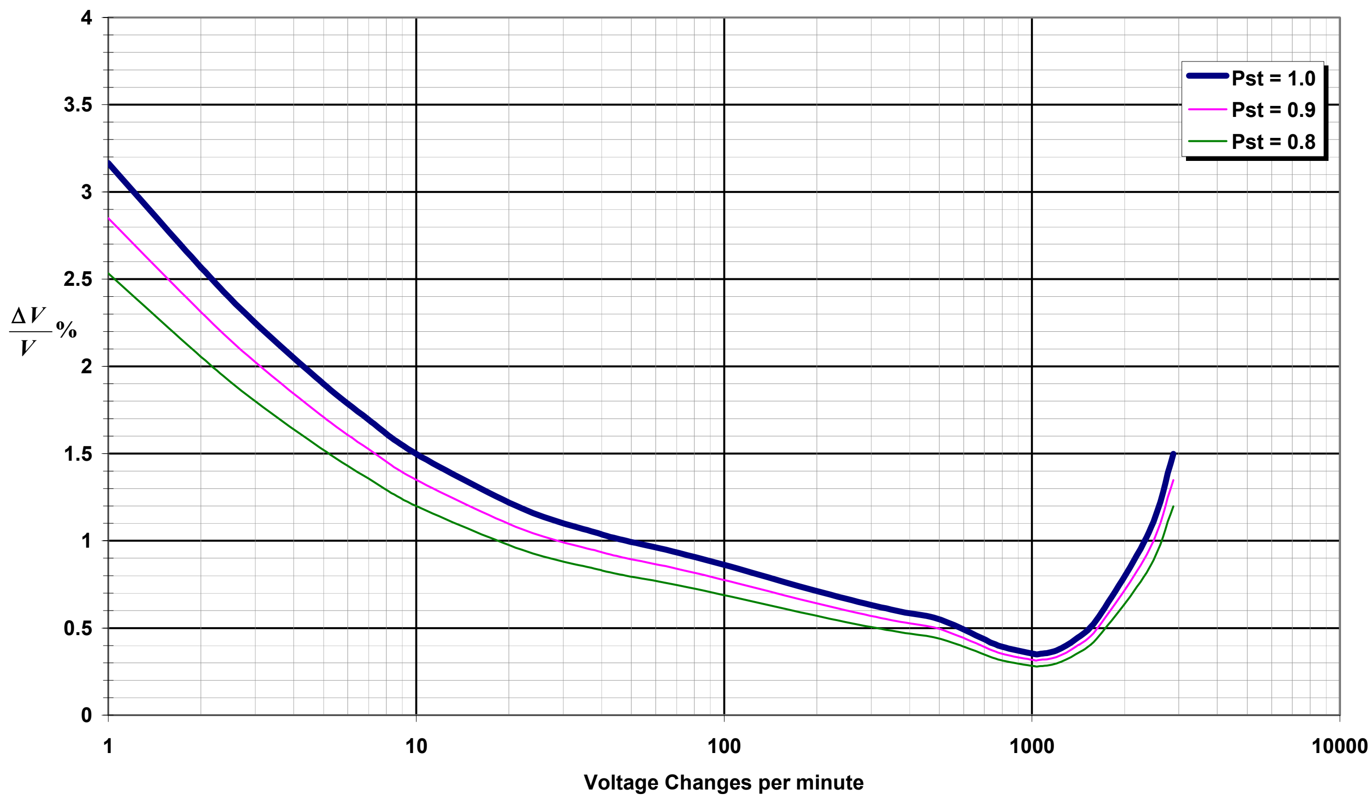


Figure 3.3.1 – CAN/CSA E1000-2-2-97 Flicker Curve For Periodic Voltage Fluctuations.

Notes:

1. The values were obtained experimentally through rectangular modulation of the 60 Hz AC waveform.

2. The human eye is most sensitive to fluctuations occuring at 8Hz, or 16 voltage changes per second. To convert the horizontal scale to fluctuations/sec. (Hz), divide by 120.

3. To meet the limits table 3.3.1, the %ΔV/V must fall on or below the corresponding P_{ST} curve, at the projected fluctuation rate. For loads with varying fluctuation rates (eg. arc furnace) %ΔV/V should be checked against a representative range of fluctuation rates.

4. See Appendix 2 for an enlarged version of the upper frequency range.

3.4 Application

3.4.1 Customers With Multiple Flicker Producing Loads

In some cases, customers may have more than one flicker producing load. The cumulative impact at the PCC is determined as follows:

For dynamic fluctuations:

- Starting restrictions in Table 3.3.3 have been conservatively selected to account for multiple voltage fluctuations
- For customers connecting multiple motors at PCC voltages 25kV and less, the %voltage fluctuation is calculated based on the largest motor. Motors cannot be started simultaneously.
- For multiple motors connected at PCC voltages greater than 24kV, cumulative flicker is calculated using the methods described in IEC standard 1000-3-7.

For periodic fluctuations:

- The cumulative effect of operating 2 or more arc furnaces, for example, will be evaluated using the methods described in IEC standard 1000-3-7 regardless of the system voltage.

3.4.2 Predicting P_{ST} Levels

For loads that produce periodic flicker, the P_{ST} emission level of an individual load can be predicted using a 2 step process.

Step 1: determine the %change in voltage fluctuation and fluctuation frequency

This requires the short circuit level and in-depth knowledge of the load and its operating characteristics. In some cases, applying the appropriate shape factor (see IEC 1000-3-7) may also be necessary. For arc furnaces, the fluctuation frequency is not constant and multiple frequencies will have to be examined.

Step 2: determine the P_{ST} level

Due to the linear relationship between the P_{ST} level and the flicker curve, the P_{ST} can be determined directly from the flicker curve in figure 3.3.1. For example, if the %ΔV/V = 0.7% with a frequency of 40 changes/minute, the expected P_{ST} level is 0.66.

Note: Manitoba Hydro will supply the short circuit level at the PCC. The customer is expected to provide the projected voltage fluctuation and fluctuation frequency (rate)

Several flicker levels can be added together using the following formula:

$$Total\ P_{ST} = \sqrt[3]{\sum_i P_{ST_i}^{\ 3}}$$

3.4.3 Measuring Voltage Fluctuations and Flicker Levels

Background flicker levels and voltage fluctuations shall be measured by:

- capturing the inrush current and voltage sag event at the customer's PCC using a power quality device capable of capturing high speed events.
- measuring the overall flicker level (P_{ST} and P_{LT}) over a representative measurement period.

The flicker level shall be measured using a power quality device that meets the requirements of the IEC flickermeter standard 61000-4-15. A graph of the cumulative frequency vs. P_{LT} shall be at or below the limits in Table 3.3.1, 99% of the time.

Using the RMS waveform from the voltage sag event, the maximum voltage change for dynamic fluctuations shall be calculated by subtracting the minimum RMS voltage from the steady-state pre-voltage:

$$\%\text{voltage change} = \frac{U_1 - U_2}{U_1} \times 100\%$$

where U_1 and U_2 are shown in figure 3.4.1.

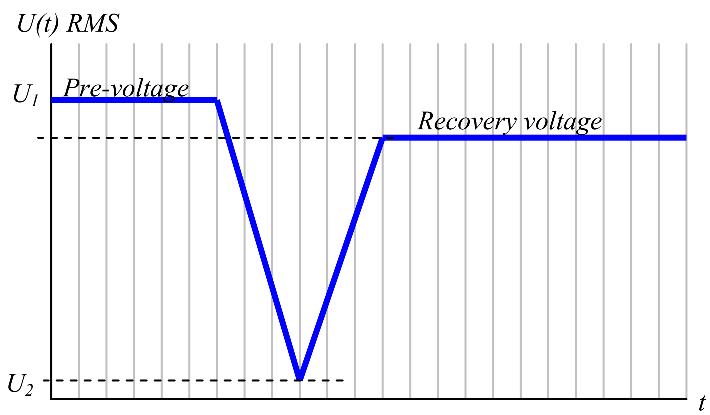


Figure 3.4.1 – RMS voltage profile of a dynamic voltage fluctuation.

The data from a flicker measurement shall be evaluated using a cumulative frequency method. This is explained in Appendix 3.

Appendix 1 – Bibliography

IEEE Std. 519: "IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems", 1992

IEEE P519A/D6: "Guide For Applying Harmonic Limits on Power Systems", January, 1999. (This guide is still in draft)

IEEE Std. 776-1992: "IEEE Recommended Practice for Inductive Coordination of Electric Supply and Communication Lines

CSA-C22.2 No.0.16-M92: "Measurement of Harmonic Currents", 1992

CSA-C22.3 No.3: "Inductive Coordination", 1954 and No. 3.1: "Inductive Coordination Handbook", 1974. (This standard is currently under review)

CEA-220 D 711: "Power Quality Measurement Protocol, CEA Guide To Performing Power Quality Surveys – 1st Edition", May 1996

CEA: "A Guide For Flicker Control In Distribution Systems", September 1981

CEA 220 D 711: "Power Quality Measurement Protocol, CEA Guide To Performing Power Quality Surveys – 1st Edition", May 1996

CEA 9134 U 861: "Light Flicker Due To Short Duration Supply Voltage Fluctuations", October, 1996

IEC 1000-3-5: "Limitation of voltage fluctuations and flicker in low-voltage supply systems for equipment with rated current greater than 16A.", 1994

IEC 1000-3-7: "Assessment of emission limits for fluctuating loads in MV and HV power systems – Basic EMC publication", 1996

IEC 61000-4-15 (1997), "Testing and measurement techniques—Section 15: Flickermeter—Functional and design specifications," Geneva, 1997

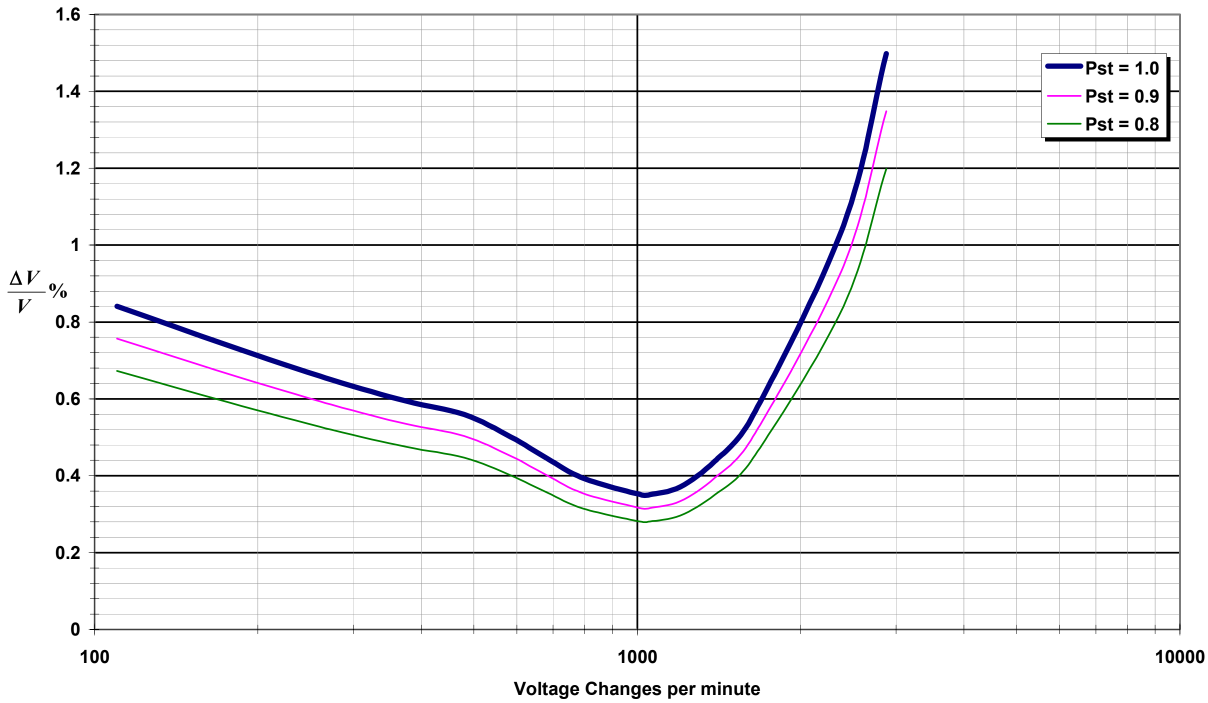
IEC 60868-0 (1990), Amendment 1. Flickermeter. "Functional and design specifications"

CAN/CSA-E1000-2-2-97: "Part 2: Environment Section 2: Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems" Sept. 1997

IEEE Power Engineering Society: Tutorial on Voltage Fluctuations and Lamp Flicker in Electrical Power Systems #01TP151

Note:
CSA = Canadian Standards Association
CEA = Canadian Electrical Association
IEEE = Institute of Electrical and Electronics Engineers
IEC = International Electrotechnical Commission

Appendix 2 – CAN/CSA E1000-2-2-97 Flicker Curve For Periodic Voltage Fluctuations (100 – 3000 changes/min.)



Appendix 3 – Cumulative Frequency Analysis

The flicker data collected during a 7-day benchmark measurement is sometimes difficult to analyze (see top graph below). As a result, it is best analyzed by plotting the PST values in a cumulative frequency graph. From this graph, the number of PST values above or below a particular threshold can be determined. (see bottom graph below)