



## **System Standard For the Installation of New Loads**

### ***Preface***

The purpose of this standard is to ensure the successful installation and connection of new loads to the ATCO Electric Distribution<sup>1</sup> system. For connection of loads directly to the Transmission system the following document (or its latest revision) should be consulted:

“Generation and Load Interconnection Standard – Rev 1 Final”

Located at the AESO (Alberta Electric System Operator) website:

<http://www.aeso.ca>

A Transmission connection implies the PCC<sup>2</sup> is at the HV level. This standard is restricted to PCCs on the ATCO Electric Distribution system.

The loads can be non-linear loads<sup>3</sup>, for example Variable speed drives (VFDs), static rectifier loads, induction furnaces or linear loads, for example large induction motor loads.

This standard outlines the technical requirements and procedures to be observed from the initial design stages to the energization of the new load and throughout the life of the facility.

Under this standard, ATCO Electric will analyze new load additions to ensure the new loads and the power system will have **ElectroMagnetic Compatibility (EMC)**. The definition of electromagnetic compatibility is per International Electrotechnical

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<sup>1</sup> Distribution voltages: Medium (MV) and Low Voltage (LV) up to and including 25 kV anything above 25 kV is Transmission (HV).

<sup>2</sup> PCC Point of Common Coupling – see Glossary

<sup>3</sup> Linear loads are those where the load current has the same shape as the voltage supply waveform. Non-linear loads do not have this equivalence. See Glossary for more information.

Commission (IEC) 61000 series of standards which form the basis of CAN/CSA C61000 series<sup>4</sup>:

“The ability of a device, equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything within that environment”

Furthermore, the new load must have certain immunity, that is, the “ability to perform without degradation in the presence of electromagnetic disturbances”.

It is the particular feature of electricity that, in respect of some of its characteristics, its quality is affected by the Consumer rather than by the utility. This is particularly true for non-linear loads. As the standards in this field evolve and harmonize, this document is based upon the most recent CSA/IEC standards. Please note the ATCO Electric modifications take precedence.

ATCO Electric will monitor recently added loads that fall within the scope of this standard to ensure the EMC environment has not been impacted in a negative way. As well, ATCO Electric will investigate if another Consumer in the area complains of power quality problems.

Significant deviations from the requirements set forth in this standard may result in the Consumer having the offending load disconnected until such infraction is corrected. The load would remain disconnected until ATCO Electric verifies that the requirements within this standard have been met. Litigation arising due to damage caused by exceeding the limits specified within this document, either to other Consumers or to ATCO Electric equipment, will be the sole responsibility of the violating Consumer.

For more information, please contact your ATCO Electric Consumer Representative.

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<sup>4</sup> With Canadian deviations

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## **Section 1 – Initial Consumer Contact**

### 1.1 Initial Information required by ATCO Electric

ATCO Electric requires the following Consumer project details:

- 1) Location
- 2) Size of total addition to the plant load plus any existing load, if sharing a mutual Point of Common Coupling (PCC)<sup>5</sup>.
- 3) Nature of the load addition for example linear or non-linear, or mixed.
- 4) Type and KW/KVA of all new and existing non-linear load(s) greater than 2% of the total plant load
- 5) Any existing or planned capacitor or passive filter banks (KVAR) with locations specified.
- 6) Any series passive filtering
- 7) Any power electronics based mitigation device such as an active filter, SVC or similar device

### 1.2 Categories for Load additions

ATCO Electric will determine which of the following categories a project will be classified under:

**Category A:** Includes a Consumer that meets the screening criteria outlined in section 1.3 below. If the Consumer meets Section 1.3, ATCO Electric will not do any harmonic analysis of the Consumers' facilities, however other types of analysis may be required. Most linear loads will fall in this category. Consumers in this class must follow the procedure outlined in Section 2 - Category A Consumer Procedure.

**Category B:** Includes all Consumers that do not meet the screening criteria in Section 1.3. Most non-linear loads will fall into this category. Consumers in this class must follow the procedure outlined in Section 3 - Category B Consumer Procedure.

### 1.3 How to determine your project category

The Consumers' project must meet each of the following criteria to be classified as Category A, otherwise the Consumer's project is classified Category B:

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<sup>5</sup> Point of Common Coupling (PCC) See Glossary for more information

- 1) The sum of the weighted harmonic loading,  $S_{D_{wi}}$  divided by the system short circuit level,  $S_{sc}$  (3 $\Phi$  fault MVA), at the PCC, must be less than 0.1%. This is per CAN/CSA C61000 3-6:04 Section 7.1.1. See Note 1.0 below.
- 2) The sum of the weighted harmonic loading,  $S_{D_{wi}}$ , divided by the total plant load,  $S_i$  must be less than 10%. In general, all loads that exceed 10% will be reviewed. See Note 1.
- 3) The Consumer shunt capacitor banks must satisfy the following condition:

$$\begin{aligned}
 |h_{\text{resonance}} - h| &> 0.35 \text{ for } h = 5, 7, 11, 13, 17 \text{ [Characteristic harmonics]} \\
 |h_{\text{resonance}} - h| &> 0.10 \text{ for } h = 2, 4, 6, 8, 10 \text{ [Even harmonics]} \\
 |h_{\text{resonance}} - h| &> 0.15 \text{ for } h = 3, 9, 15, 21, 27 \text{ [triplen harmonics]}
 \end{aligned}$$

Frequencies are in per unit (Base frequency is 60 Hz). See Note 2

**Note 1:** Weighting of the various harmonic loads will be completed using Table A2 in the Appendix. This Table is reproduced from CAN/CSA C61000 3–6:04 Section 7.0. If the characteristics of the harmonics producing load are unknown, weighting of 2.5 should be assumed.

**Note 2:** Any shunt capacitor within a harmonic environment that doesn't meet the criterion should be detuned using a series reactor or converted into a C Class filter.

## 1.4 References and Standards

The main references relevant to this Standard are:

- [1] CSA CAN3 C235-83 Preferred Voltage Levels for AC Systems 0 to 50000 V<sup>6</sup>
- [2] IEEE Std 519-1992 IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
- [3] IEC 1000-1-1 Electromagnetic Compatibility (EMC) Part 1: General Section 1: Application and interpretation of fundamental definitions and terms
- [4] CAN/CSA CEI/IEC 61000-2-4:04 Electromagnetic Compatibility (EMC) Part 2-4: Environment - Compatibility levels in industrial plants for low frequency conducted disturbances

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<sup>6</sup> With extended definition per CEA 220 D 711 “Power Quality Measurement Protocol “

- [5] CAN/CSA C61000-3-6:04  
Electromagnetic Compatibility (EMC) Part 3: Limits  
Section 6: Assessment of emission limits for distorting loads in  
MV and HV Power systems - Basic EMC publication
- [6] CAN/CSA C61000-3-7:04  
Electromagnetic Compatibility (EMC) Part 3: Limits  
Section 7: Assessment of emission limits for fluctuating loads in  
MV and HV Power Systems – Basic EMC publication
- [7] IEC 61000-4-15 Electromagnetic Compatibility (EMC) Part 4: Testing and  
Measurement Techniques  
Section 15: Flickermeter – Functional and design specifications
- [8] CAN/CSA – E1000-2-2-97 Reaffirmed 2001  
Electromagnetic Compatibility (EMC)  
Part 2: Environment  
Section 2: Compatibility levels for low-frequency conducted  
disturbances and signaling in public low voltage power supply  
systems
- [8] IEEE Std 1159-1995 IEEE Recommended Practice for Monitoring Electric  
Power Quality
- [9] CAN/CSA – CEI/IEC 61000-4-7:03  
Electromagnetic Compatibility (EMC) Part 4-7: Testing and  
Measurement Techniques-  
General guide on harmonics and interharmonics measurements and  
Instrumentation, for power supply systems and equipment  
connected thereto
- [10] CEA Publication 220 D 711 Power Quality Measurement Protocol  
CEA Guide to Performing Power Quality Surveys

## **Section 2 - Category A Consumer Procedure**

### 2.1 Introduction

This section outlines the procedure for linear load additions defined in Section 1 – Initial Consumer Contact. The Category A Consumer will impact system RMS voltage performance, and potentially voltage flicker and voltage unbalance.

Linear load additions will follow the existing procedures within ATCO Electric. The purpose of the existing procedures is to ensure adequate line capacity is available for handling the proposed load. In addition, motor start studies may be carried out to determine the maximum allowable Hp ratings for across the line or reduced voltage starting. There are two voltage sag criteria for motor starting:

1. The minimum sag voltage shall not be allowed to fall below 91.6% of nominal voltage at the PCC. The voltage anywhere else on the line cannot fall below 90.0% (excluding the Transmission Substation MV Bus). To meet these criteria may necessitate system improvements. The utilization voltage sag will be deeper and must be tolerable to the Consumer's own equipment.
2. The minimum sag voltage at the Transmission Substation(s) serving the Distribution system shall not change by more than 5% of its regulated 25 kV voltage.

As an example, the voltage at the substation cannot fall more than 5%, the source side voltage on a regulator or series capacitor cannot fall below 90% of nominal and at the PCC, and the voltage cannot fall below 91.6% of nominal. Determination of whether the motor can accelerate safely to synchronous speed under these voltage sag conditions remains the responsibility of the Consumer. In addition there are flicker limits as detailed in Section 6.4. Also, the swell voltage cannot exceed 105% of nominal at any point on the line during the start.

ATCO Electric will be involved with the Consumer from project inception and throughout its lifecycle. ATCO Electric will not be responsible for any Consumer design engineering. ATCO Electric will provide the necessary system information so that the Consumer can engineer, or have the project engineered to meet this standard. ATCO Electric's involvement will be to satisfy the Consumer's electrical supply needs while ensuring the Consumer's project has no adverse effects on other existing or potential Consumers or the electrical supply system.

ATCO Electric will sign a project confidentiality agreement with the Consumer if the Consumer deems that such an agreement is necessary.

## 2.2 Procedure and Information exchange during design stages

Effective communication should begin prior to the Bid specification for the linear loads. The performance limits outlined in Sections 4.0 to 6.0 of this document may be copied and forwarded to prospective equipment suppliers. ATCO Electric will provide:

- a) Short circuit levels at the PCC
- b) The maximum voltage unbalance (defined per IEEE 1159)
- c) System information requested by the Consumer

After award of the contracts, the following information should be forwarded to ATCO Electric:

- 1) Single line diagram of the plant installation (Appendix A4)
- 2) Confirmation of details regarding the plant load including
  - size of the total plant load addition (complete with load factors)
  - size of any existing load sharing the PCC
  - type, KW/KVA, and motor start up profiles of all new loads including motor speed/torque startup characteristics, inertias of motor and driven load
  - motor starting method for example autotransformer, series reactor, shunt capacitor assist, soft start or VFD start (See Note 3)
- 3) Any capacitor (including surge and power factor correction capacitor) location and rating (including voltage rating)

Within one month of supplying the above information, ATCO Electric will confirm the following information:

- 1) The maximum allowable motor size for across the line or reduced voltage starting
- 2) System information requested by Consumer

ATCO Electric will be available to discuss with the Consumer all technical details regarding the ATCO Electric system and this document after project initiation.

During the final design, the Consumer must confirm that all technical details previously provided are still correct. These final design specifications will be used by ATCO Electric to verify the system analysis and consequently bring closure to ATCO Electric's engineering designs. Any concerns by ATCO Electric will be discussed with the Consumer within one month after submission of the final design.

**Note 3:** The use of a soft starter or VFD start with eventual synchronization to the line will change the Category A classification to Category B.

## **Section 3 - Category B Consumer Procedure**

### **3.1 Introduction**

This section outlines the procedure for all non-linear load additions defined in Section 1 – Initial Consumer Contact. The Category B Consumer potentially has the biggest impact on the system performance. It should be noted, that Category B requirements are in addition to those requirements for Category A Consumers.

ATCO Electric will be involved with the Consumer from project inception and throughout its lifecycle. ATCO Electric will not be responsible for any Consumer design engineering. ATCO Electric will provide the necessary system information so that the Consumer can engineer, or have the project engineered to meet this standard. ATCO Electric's involvement will be to satisfy the Consumer's electrical supply needs while ensuring the Consumer's project has no adverse effects on other existing or potential Consumers or the electrical supply system.

ATCO Electric will sign a project confidentiality agreement with the Consumer if the Consumer deems that such an agreement is necessary.

### **3.2 Procedure and Information exchange during design stages**

Effective communication should begin prior to the Bid specification for the non-linear loads. The performance limits outlined in Section 6.0 along with measurement criteria in Sections 4.0 to 5.0 of this document may be copied and forwarded to prospective equipment suppliers. ATCO Electric will provide:

- 1) Short circuit levels at the PCC
- 2) The maximum voltage unbalance (defined per IEEE 1159)
- 3) System information requested by the Consumer

After award of the contracts, the following information should be forwarded to ATCO Electric:

- 1) Single line diagram of the plant installation (Appendix A4)
- 2) Details on all transformers (size, connection, impedance, tappings) , cables and other linear loads
- 3) Confirmation of details regarding the plant load including
  - size of the total plant load addition (complete with load factors)
  - size of any existing load sharing the PCC

- type, KW/KVA, and current harmonic profile of all new and existing non-linear loads greater than 2% of the total plant load
- 4) For adjustable speed drives (ASDs) or Variable Frequency Drives (VFDs):
- type, rating and range of operation (output voltage, current and frequency)
  - Pulse number
  - AC front end reactor choke (if any) in millihenries
  - DC Bus smoothing capacitor size in microfarads, and reactor size in millihenries
  - Operational procedures for energization and load rejection including filter switching
  - Any front end filter component details and tuned frequencies (passive shunt or series, active filters)
  - Startup sequence along with inrush current if applicable for higher pulse number drives
- 5) Any capacitor (including surge and power factor correction capacitor) location and rating (including voltage rating)

Within 1.5 months of supplying the above information, ATCO Electric will give the Consumer the following information:

- 1) Harmonic impedance envelope which will include known and future area plans
- 2) Harmonic Emission Limits (See Section 6.10) if applicable
- 3) Background %DF voltage in the vicinity of the PCC (if requested and obtainable)
- 4) System information requested by Consumer

The Consumers' equipment supplier will require this information to complete the design.

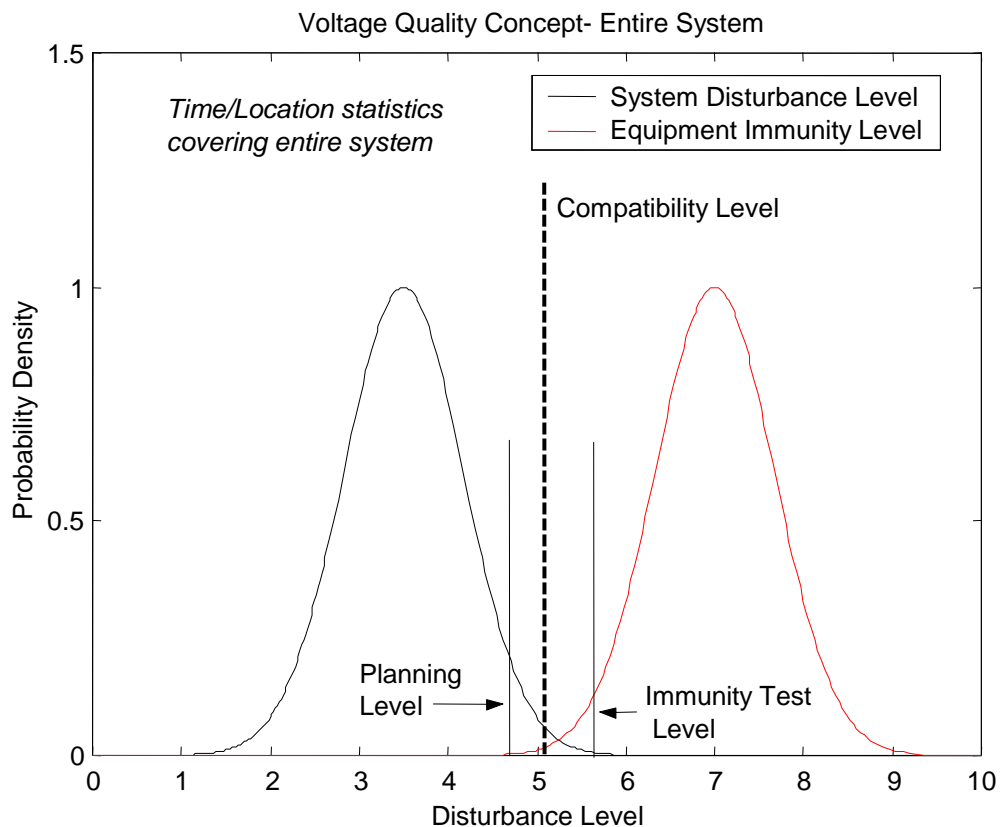
ATCO Electric will be available to discuss with the Consumer all technical details regarding the ATCO Electric system and this document after project initiation.

During the final design, the Consumer must confirm that all technical details previously provided are still correct. The final design specifications will be used by ATCO Electric to verify system studies and consequently bring closure to ATCO Electric's engineering design. Any concerns by ATCO Electric will be discussed with the Consumer within one month after submission of the final design.

## Section 4 - CSA Standard Overview

The ATCO Electric standard is based upon CSA/IEC standards. CSA has adopted many of the IEC 1000 series standards (with very little modification) as National Standards of Canada. The basic structure of the IEC standard will be reviewed briefly in this section.

First and foremost it is important to realize the IEC standards are based upon voltage quality. As mentioned in the Preface the concept of EMC is central to this approach. Certain types of Consumer load will inject (inter)harmonic currents and voltages into the public system which over time will cause cumulative deterioration of voltage quality. A drop in voltage quality could be damaging or may cause a loss of function for more sensitive equipment. This implies emission limits for individual equipment or a Consumer's load should be developed on the basis of voltage quality criteria. The voltage quality criteria arise as Compatibility Levels which are reference values for coordinating the emission and immunity of equipment which is part of, or supplied by, supply network in order to ensure EMC in the whole system. The basic concept is shown in *Figure 1.0*.



*Figure 1.0* Illustration of basic voltage quality concept

In *Figure 1.0*, the distribution function on the left represents the system disturbance level such as %VTHD. The Planning level is chosen by the utility to represent the 95% probability<sup>7</sup> of not exceeding the disturbance level. The immunity level (failure curve) for the equipment is shown on the right. The immunity test level represents perhaps the 5% probability that equipment could fail if the disturbance level were maintained at that value. The actual probability of failure would be the overlap area of the two distributions which should be very small. Central to the concept is a defined Compatibility Level.

Though the emphasis in this standard is focused on the public supply system, these same concepts can be extended to the industrial environment. Standard CAN/CSA CEI/IEC 61000-2-4:04 deals with this extension. Three classes are defined:

- Class 1 Applies to protected supplies and has Compatibility levels lower than those on public networks (ATCO Electric). It relates to equipment very sensitive to disturbances for example Data Centers.
- Class 2 Applies generally to a PCC or IPC<sup>8</sup> in the environments of industrial and other non public power supplies, Compatibility levels are generally identical to those of public networks
- Class 3 Applies only to IPCs in industrial environments, it has higher compatibility levels than Class 2 for some disturbances phenomena. This class would be typical of plants with large VFDs, welding machines, frequent large motor starting etc.

In practice, these classes cannot be totally isolated from each other since there is usually an interface point with the utility (the service entrance) and emission limits must be controlled at this point. As an example, light ballasts that continue to fail in a Class 3 environment may have only a Class 2 Compatibility level.

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<sup>7</sup> Area under the curve from 0 to the Planning Level

<sup>8</sup> In Plant Point of Coupling, IPC, see Glossary for more information

## Section 5 - Compliance Testing

### 5.1 Introduction

ATCO Electric will carry out compliance measurements both before and after the Consumer has commissioned his facility.

The key performance indices identified in Section 6 will be sampled and results reduced to their statistical norms as shown in *Figure 2.0*, which represents an actual set of measurements. From *Figure 2.0*, the Cumulative Probability function (CPF) may be generated as shown in *Figure 3.0*. The minimum monitoring period will be 1 week so as to cover the complete load cycle.

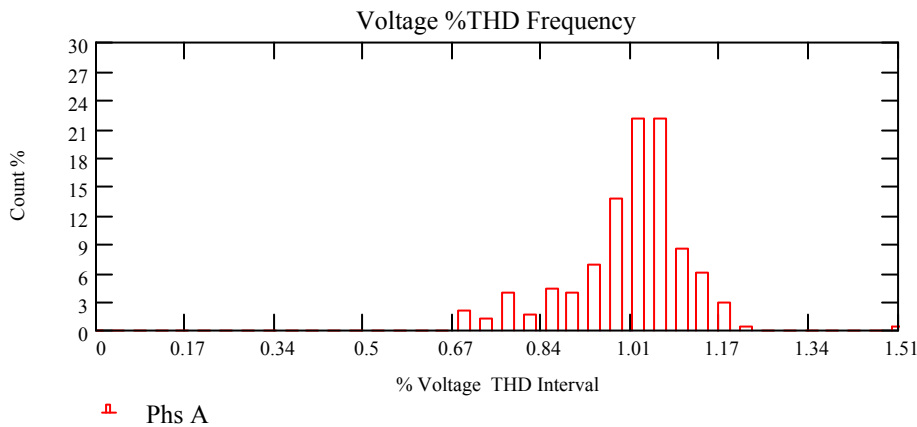


Figure 2.0 Histogram of Voltage %THD Readings

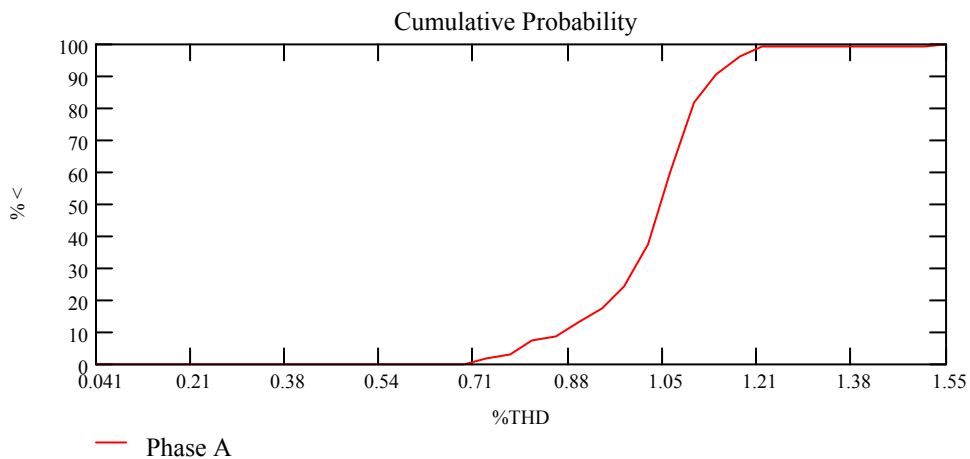


Figure 3.0 Cumulative Probability function of %THD from Figure 2.0

Compliance is achieved if the cumulative probability for the Index is less than the Planning Level given in Section 6. From *Figure 3.0* it can be seen the %THD Voltage is less than 1.18% approximately 96.4% of the time. This value is well within the 6.5% distribution limit within this Standard.

By comparison of the relevant steadystate performance indices both before and after the load addition, the impact on the supply system can be assessed. In cases of non-compliance with the Planning levels, a more detailed analysis may be required to isolate the new load's contribution to the overall index.

It should be noted that the main purpose of compliance checking is to ensure that the normal operating characteristic of the load doesn't conflict with the EMC requirements of the supply system as reflected in the performance indices. Thus the somewhat artificial load levels imposed during commissioning, though useful, become not as relevant. The main focus is upon what the actual load behavior is 95% of the time. This approach allows some leeway if the Planning Levels are only exceeded during startup or during infrequent loading conditions. If the revenue metering load profile shows a distinct change in the operating load, compliance checking could be repeated.

In order to compare a consumer's (inter)harmonic levels with Planning Levels; the minimum measurement period should be one week.

- The greatest 95% daily value of  $U_{h,vs}$  (RMS value of individual harmonic components over very short 3 sec periods) should not exceed the planning level.
- The maximum weekly value of  $U_{h,sh}$  (RMS value of individual harmonics over "short" 10 minute periods) should not exceed the planning level.
- The maximum weekly value of  $U_{h,vs}$  should not exceed 1.5 times to 2 times the planning level.

Except for steady state voltage limits, voltage flicker and voltage unbalance, most of the performance indices follow the same assessment criteria above.

## 5.2 Test Protocols

The preferred test instrument will conform to the CSA Power Quality Protocol which is based upon RMS calculation of each performance index over a synchronous contiguous 12-cycle window. The 12 cycle window has been adopted in the IEC standards for 60 Hz systems. This 12 cycle data can then be processed into 3 second, 10 minute and 2 hour interval data for each index<sup>9</sup>. As the interval increases, the Index RMS value will tend to decrease. In particular, harmonic and interharmonic measurements should follow CAN/CSA – CEI/IEC 61000-4-7:03.

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<sup>9</sup> Not all indices lend themselves to this approach. Exceptions would be the Flicker Calculation, Time durations for voltage dips etc.

As not all existing test equipment meets the CEA Protocol, a similar but less rigorous analysis based upon snapshots taken every few minutes can be carried out. In cases where the results are marginal, the testing may be repeated per the more rigorous CEA Protocol with the preferred test instrument.

### 5.3 Emission Levels (Harmonics and Interharmonics)

At each (inter)harmonic frequency, the emission level from a distorting load is the (inter)harmonic voltage (or current) which would be caused by the load into the power system if no other distorting load was present.

In order to compare a Consumer's total load harmonic current emission with the emission limits, the minimum measurement period should be one week.

- The greatest 95% daily value of  $I_{h,vs}$  (RMS value of individual harmonic components over very short 3 sec periods) should not exceed the emission limit.
- The maximum weekly value of  $I_{h,sh}$  (RMS value of individual harmonics over "short" 10 minute periods) should not exceed the emission limit.
- The maximum weekly value of  $I_{h,vs}$  should not exceed 1.5 times to 2 times the emission limit
- Short duration bursts of harmonics (duration <3 sec) are to be limited, with respect to mains signaling systems (ATCO Electric's Automated Meter Reading system).

The emission limits will depend upon the Consumer and are based upon not exceeding the Planning levels assigned to limit the (inter)harmonic voltage at the PCC or IPC. Section 6.10 discusses assignment of emission limits.

### 5.4 Compliance Report

The compliance report will contain the following information:

- 1) Site Identification
- 2) The relevant measurement quality indices are summarized and compared to limits
- 3) Interpretation of results
- 4) Conclusions
- 5) Appendices – background information, glossaries etc.

Those indices that lend themselves to steadystate measurements are well represented in such a survey. Problems of a transient nature tend to be representative of abnormal operating conditions and will not be adequately represented in a proper statistical way by such a survey. A longer monitoring period with other types of test equipment may be required.

## Section 6 - Performance Requirements

### 6.1 Introduction

The performance indices most relevant to establishing a performance metric for the power system and Consumer will now be presented. The Planning levels are the target levels the utility wishes to maintain to ensure the overall electromagnetic environment is compatible with both the Consumers' and utility equipment.

### 6.2 Steadystate Voltage Limits

ATCO Electric maintains the steadystate voltage within the following limits as stipulated in CSA CAN3 C235. Table 1.0 is extracted from this standard. The sample time duration is 10 minutes and the probabilities are per the CEA PQ Protocol [9].

Type	Low <i>SUPE</i> <sub>99</sub> 99.9%	<i>SUPE</i> <sub>95</sub> 95%	Declared V <sub>d</sub>	<i>SOPE</i> <sub>95</sub> 95%	<i>SOPE</i> <sub>99</sub> 99.9%
Single phase	106	110	120	125	127
	212	220	240	250	254
	424	440	480	500	508
	530	550	600	625	635
Three phase 4 Conductor V <sub>ln</sub> /V <sub>pp</sub> Volts	110/190	112/194	120/208	125/216	127/220
	220/380	224/194	240/416	250/432	254/440
	245/424	254/440	277/480	288/500	293/508
	306/530	318/550	347/600	360/625	367/635
Three Phase 3 conductor V <sub>pp</sub> Volts	212	220	240	250	254
	424	440	480	500	508
	530	550	600	625	635
% 10minute	<b>-11.7</b>	<b>-8.3</b>	-	<b>+4.2</b>	<b>+5.5</b>

**Table 1.0** Voltages recommended by CSA CAN3 C235

Table 1.0 states that 99.9% of the time the utility will not drop below *SUPE*<sub>99</sub> and that 95% of the time, the utility will not drop below *SUPE*<sub>95</sub>. According to IEEE std. 1159, long duration voltage variations are greater than 1 minute; thus these indices will capture these variations.

### 6.3 Harmonic Voltage Limits for the Utility

Both the Consumer and ATCO Electric are jointly responsible for ensuring the harmonic voltage distortion limits are met. Together, they will ensure that the harmonic distortion for individual voltage harmonics will not exceed the values listed in Table 2.0 for 95% to 99.99% of the time. The values are in RMS with sampling intervals of 3 seconds and 10 minutes. For those loads having a PCC on the MV (distribution) network, the limits in Table 2.0 apply.

The power system is capable of absorbing a certain amount of harmonic distortion without exceeding these levels, thus as the loading is increased on a feeder, the background distortion levels are expected to rise. A new load addition cannot cause the voltage distortion to exceed these limits<sup>10</sup>. The limits will apply on a per phase basis at the PCC under all steady state load conditions.

<b>Harmonic Order</b>	<b>%Fundamental Level at 95% Probability</b> <i>IVH<sub>n(3s)</sub></i>	<b>%Fundamental Level at 99.99% Probability</b> <i>IVH<sub>n(3s)</sub></i>	<b>%Fundamental Level at 99.99% Probability</b> <i>IVH<sub>n(10min)</sub></i>
2	1.6	2.4	1.6
4	1.0	1.5	1.0
6	0.5	0.75	0.5
8	0.5	0.75	0.5
10	0.5	0.75	0.5
12	0.5	0.75	0.5
>12 (even)	0.5	0.75	0.5
3	4	6.0	4
5	5	7.5	5
7	4	6	4
9	1.2	1.8	1.2
11	3	4.5	3
13	2.5	3.75	2.5
15	0.3	.45	0.3
17	1.6	2.4	1.6
19	1.2	1.8	1.2
21	0.2	0.3	0.2

<sup>10</sup> Under certain conditions when all the potential new loads are known, especially when new feeders are added, the utility can often reduce overall voltage distortion by modifying the system design. Historically, the unpredictability of new loads on an existing feeder has favored the first come, first serve approach, however some allocation of capacity is warranted even under this approach.

23	1.2	1.8	1.2
25	1.2	1.8	1.2
27	0.7	1.05	0.7
29	.63	.95	.63
31	.60	.90	.60
33	.59	.87	.59
35	.56	.84	.56
37	.54	.81	.54
39	.52	.78	.52
41	.50	.76	.50
43	.49	.74	.49
45	.48	.72	.48
47	.46	.70	.46
49	.45	.68	.45

**Table 2.0** Planning Levels for Individual Voltage Harmonic Limits per CAN/CSA C61000 3-6:04 for MV networks

#### 6.4 Voltage Fluctuations

Voltage fluctuations are a systematic variation of the voltage envelope or a series of random voltage changes that generally stay within the normal (-8.3 to 4.3%) steadystate operating voltages given in Table 1.0. A rapid variation in load current will lead to voltage fluctuations that become noticeable as variations in lighting intensity.<sup>11</sup> This variation in the luminance of lamps can create the visual phenomena called flicker. Above a certain threshold flicker becomes annoying. The annoyance grows very quickly with the amplitude of the fluctuation. At certain repetition rates even very small amplitudes can be annoying. IEC 1000 3-3 covers voltage fluctuations and has been accepted by the IEEE (see IEEE Std. 1159-1995).

Only instruments that comply with IEC 1000 4-15 (previously IEC 868) can carry out the measurement process. Both a short term and long term Flicker index<sup>12</sup> has been defined. Table 4.0 details the Voltage fluctuation limits as defined in CAN/CSA C61000-3-7:04.

The HV levels in Table 3.0 are suggested levels for coordination with the MV network. See the AESO Standard regarding HV flicker limits.

<sup>11</sup> Interharmonic currents produced by large VFDs can also produce a flicker problem

<sup>12</sup> The output of the meter represents a measure of Irritability in units of perceptibility, normalized to 1.0. *Pst* refers to short term flicker measured over 10 minute intervals, *Plt* refers to long term flicker measured over 2 hour intervals.

	<b>Compatibility Level LV and MV</b>	<b>Planning Level LV and MV</b>	<b>Planning Level HV</b>
<i>Pst</i>	1.0	.9	.8
<i>Plt</i>	.8	.7	.6

**Table 3.0** Flicker Index Compatibility and Planning Levels

The minimum duration for measurements is 1 week. This results in 1008 (10-minute) *Pst* readings. From the *Pst* values measured, the Cumulative Probability function (*CPF*) of *Pst* and *Plt* is calculated and the percentage *Pst95%*, *Pst99%*, *Plt95%* and *Plt99%* are derived:

- *Pst99%* should not exceed the Planning Levels
- *Plt99%* should not exceed the Planning Levels

Uncontrollable events such as faults in the power system would influence the data. These events should be discarded or monitoring extended. Unlike other performance indices, the 99<sup>th</sup> percentile is used for compliance.

The emission level from a fluctuating load is the flicker level, which would be produced in the power system if no other fluctuating load were present. The first step in a flicker determination is establishing how much the emitting load contributes to the back ground level. The procedures suggested by CAN/CSA C61000 3-7:04 will be followed for determining the emission limits.

The allowable flicker level represents a physiological limitation, which is relevant only for repetition rates exceeding 6 voltage fluctuations per hour. A motor start frequency of one startup per hour would not be considered a flicker issue if the change in voltage were less than 9%, however 9% would be considered excessive from a system viewpoint. For this reason, additional limitations on the number of allowable voltage changes per day are given in Table 4.0 for MV networks.

<b>Repetitions/hour</b>	<b>%Voltage Fluctuation (Urban)</b>	<b>%Voltage Fluctuation (Rural)</b>
r < 1	4	6
1 < r < 10	3	4
9 < r < 101	2	2.5
100 < r < 1000	1.25	1.25

**Table 4.0** Allowable Voltage Fluctuation repetition rates on a Daily Basis for MV power systems

## 6.5 Voltage Notching

For applications where the PCC is on the LV side of the transformer, the following limits on commutation notching will apply<sup>13</sup>. Notches are repetitive voltage transients with durations usually less than 1 msec that occur periodically every cycle. IEEE 519 defines notch depth as the maximum depth of the line voltage excursion from the sinusoidal wave of the voltage  $U_{nom}(t)$  across the nonlinear load. Related to notch depth is notch area (volt –microseconds) which is the notch depth times the width (in microseconds) of the notch. Under certain conditions severe notching can lead to area voltage concerns that must be immediately addressed. This is usually manifest by violations of harmonic voltage limits beyond the 31<sup>th</sup> harmonic and sometimes extra zero crossings, Table 5.0 presents the allowable maximum NDF and NAF factors.

<b>Bus Voltage</b>	<b>Notch Depth (NDF) %</b>	<b>Notch Area (NAF) Volt-microseconds</b>
120/208	20	9880
277/480	20	22800
346/600	20	28500
2400/4160	20	197600

**Table 5.0** Limits on Commutation Notches

Notching can upset electronic equipment, damage inductive components and cause telecommunication problems (IT levels being exceeded). Notch measurements should be taken during Consumer commissioning and later on once the load characteristic has stabilized.

## 6.6 Interharmonic Voltage Limits

An interharmonic is a non integer harmonic such as 92 Hz. Fourier analysis breaks down a signal into a series of perfect sine waves characterized by different frequencies. The interharmonic frequencies occur between the harmonic frequencies, between  $n$  and  $n+1$ . The CEA protocol defines how interharmonics are measured. A 12 cycle snapshot has a minimum resolution of 5 Hz and is the basis for the  $PIH_n$  measurement.

$$PIH_n = \frac{\sqrt{\sum_{.x<1} IVH_{n,x}^2}}{IVH_1}$$

<sup>13</sup> LV bus becomes dedicated converter bus.

Where  $n$  = harmonic order.

If  $n=0$ , then the RMS value of all the frequency components greater than 0 but less than 60 Hz is calculated and divided by  $IVH_1$ , the fundamental voltage magnitude. If  $n=1$ , then the RMS value of the frequency components greater than 60 Hz but less than 120 Hz is calculated. Interharmonics can lead to flicker problems with fluorescent lighting, motor vibration, interference with mains signaling and other equipment problems. Table 6.0 presents the limits.

Factor	Reference	Probability %	% limit
$PIH_n$	Partial Interharmonic of order $n$ calculated on 12 cycle window	99.99	0.60
$PIH_{n(3s)}$	Partial Interharmonic of order $n$ calculated on a 3 second window	95	.30
$PIH_{n(3s)}$	Partial Interharmonic of order $n$ calculated on a 3 second window	99.99	0.45

**Table 6.0** Limits on Partial Inter harmonic voltage

Table 6.0 states any individual  $PIH$  measurement should not exceed 0.6% over a 12 cycle interval, and similarly .30% over a 3 second interval.

With larger windows (>12 cycles) the individual interharmonic voltages may be isolated<sup>14</sup>. The **Planning limit for an individual interharmonic is 0.2%** of the fundamental at both the PCC and at the IPC closest to the ATCO Electric service entrance which is typically the ATCO Electric meter. The tight limit, dictated by CSA/IEC Standards, is required since ATCO Electric uses a mains signaling system (Automated Meter Reading).

## 6.7 Voltage Unbalance

Voltage unbalance, VUF, is applicable only to 3 phase supplies. It represents the loss of symmetry in the supply (magnitude and angle) and is calculated by measuring the ratio of negative sequence to positive sequence voltage. Voltage unbalance is mainly caused by unequal loading of the voltage phases. Both power electronic and induction motor loads are affected by voltage unbalance. For motors, there is an increase in circulating current leading to additional heat loss and consequent temperature rise. The instantaneous value of the VUF is not as important as its long term average value. A ten minute interval is used for assessing VUF. Table 7.0 presents the limits.

<sup>14</sup> Provided the window waveform must remain reasonably stationary

Factor	Reference	Probability %	% limit
$VUF_{3s}$	Voltage Unbalance recorded in 3-s interval	99.9	4.5
$VUF_{3s}$	95% Cumulative value of voltage unbalance	95	3.0
$VUF_{10min}$	95% Cumulative value of voltage unbalance per NEMA and CENELEC	95	<b>2.0</b>

**Table 7.0** Voltage Unbalance limit MV and LV

## 6.8 Voltage Distortion

The Distortion Factor,  $DF$  is given by the following equation for integer harmonics:

$$DF = \frac{\sqrt{\sum_{n=2}^{50} IVH_n^2}}{IVH_1} \times 100\%$$

The term is similar to Total Harmonic Distortion (THD) as defined in IEEE 519 except within IEEE 519 the denominator uses the nominal voltage value such as 120V.

The applicable limits are shown in Table 8.0 for MV and LV voltage levels.

HV distortion limits are discussed within the AESO Standard. Under the CSA/IEC standard a certain portion of the MV distortion limit will be taken up by (inter)harmonic injection from the HV system. In practice the allowable MV distortion (as contributed by MV loads) may be less depending upon the circumstance.

These distortion limits do not contain the effects of Interharmonics since many instruments only count the harmonic frequencies, the actual full spectrum distortion level may be understated. By the same token, an instrument that doesn't segregate them will overstate the  $DF$  value. The full spectrum distortion factor (Total Distortion Factor) is given by:

$$TDF = \sqrt{DF^2 + \sum_n PIH_n^2}$$

Since limits for  $DF$  and  $PIH_n$  have already been defined, there are no planning limits for  $TDF$ .

<b>Factor</b>	<b>Reference</b>	<b>Probability %</b>	<b>% Limit MV and LV</b>
$DF$	Instantaneous DF based on 12 cycle window	NDA*	NDA
$DF_{3s}$	99.9% Cumulative frequency value of the RMS DF calculated in a 3 second interval	99.9	13.0
$DF_{3s}$	95% Cumulative frequency value of the RMS DF calculated in a 3 second interval	95	6.5
$DF_{10min}$	99.9% Cumulative value of RMS DF calculated in a 10 minute synchronized interval	99.9	6.5

Notes: \* No Data Available NDA

**Table 8.0** Voltage Distortion Limits per IEC 1000 3-6 for MV and LV circuits

## 6.9 Crest Factor

The Crest Factor, CF, is the ratio between peak voltage and its RMS value. In ANSI/IEEE 446-87 the crest factor should be  $1.4141 \pm 0.1$ . Excessive crest factors can affect AC/DC power supplies and the dielectric life of capacitors. There are two factors that describe Crest Factor as per IEEE 446-87:

Crest Variation Factor, CF<sub>v</sub>, describes the time variation in amplitude of the Crest Factor which should not exceed 0.5%. Higher values have been reported as causing flicker in television pictures.

Crest Amplitude Factor, CF<sub>a</sub>, describes amplitude of Crest Factor.

The limits on Crest Factor are given in Table 10.0

<b>Factor</b>	<b>Reference</b>	<b>Probability %</b>	<b>% limit</b>
$CF_v$	Crest Variation Factor per IEEE 446-1987 measured over 10 seconds	99.99	0.5
$CF_a$	Crest Factor Amplitude per IEEE 446	99.99	$\pm 7.1$

**Table 10.0** Crest Factor Limits

## 6.10 Limits on Current Distortion

The non-linear load acts as a current source for harmonics. The level of current injection in conjunction with the system impedance determines the load's contribution to the overall voltage distortion. To limit voltage distortion, current injection (emission) limits have to be imposed. As the short circuit level declines with distance on the line from the substation (increase in impedance), the allowable current injection level must decline to maintain voltage limits. For this reason usage of standard reference impedance cannot be defined. A flowchart of the procedure for defining emission limits is shown in *Figure 4.0*. This applies mainly to consumers with PCC on the MV network.

In **Stage 1** of the procedure the first decision box decides whether more work is warranted based upon the declared load:

$$\frac{S_i}{S_{sc}} < 0.1\%$$

Where

$$\begin{aligned} S_i & \quad \text{Declared Load in KVA} \\ S_{sc} & \quad \text{Short circuit level at the PCC} \end{aligned}$$

If the load is too small then an automatic acceptance is granted. Note that no conditions are placed upon the load at this stage. It may be 100% non-linear. The one exception could be a large number of identical small loads at multiple PCCs on the same feeder (each of which obeys the above criterion) could lead to undesirable load agglomeration effects that may cause the PCC voltage bus harmonic limits to be exceeded. In this situation ATCO Electric may have to specify the emission limits at each PCC (Stage 2) or consider application of an area MV filter.

The next decision box has two criteria listed:

$$\frac{S_{Dwi}}{S_{sc}} < 0.1\% \quad \text{or} \quad \frac{I_{hi}}{I_i} < I_h$$

Where

$$\begin{aligned} S_{Dwi} & \quad \text{Weighted Distorting Power (see example in Section A3)} \\ I_{hi} & \quad \text{Harmonic injection current from load at the PCC} \\ I_i & \quad \text{Rated Current of the load (agreed KVA } S_i \text{)} \\ I_h & \quad \text{Current Limit as shown in Table 11.0 (IEEE 519) if load is less than 500 kVA.} \end{aligned}$$

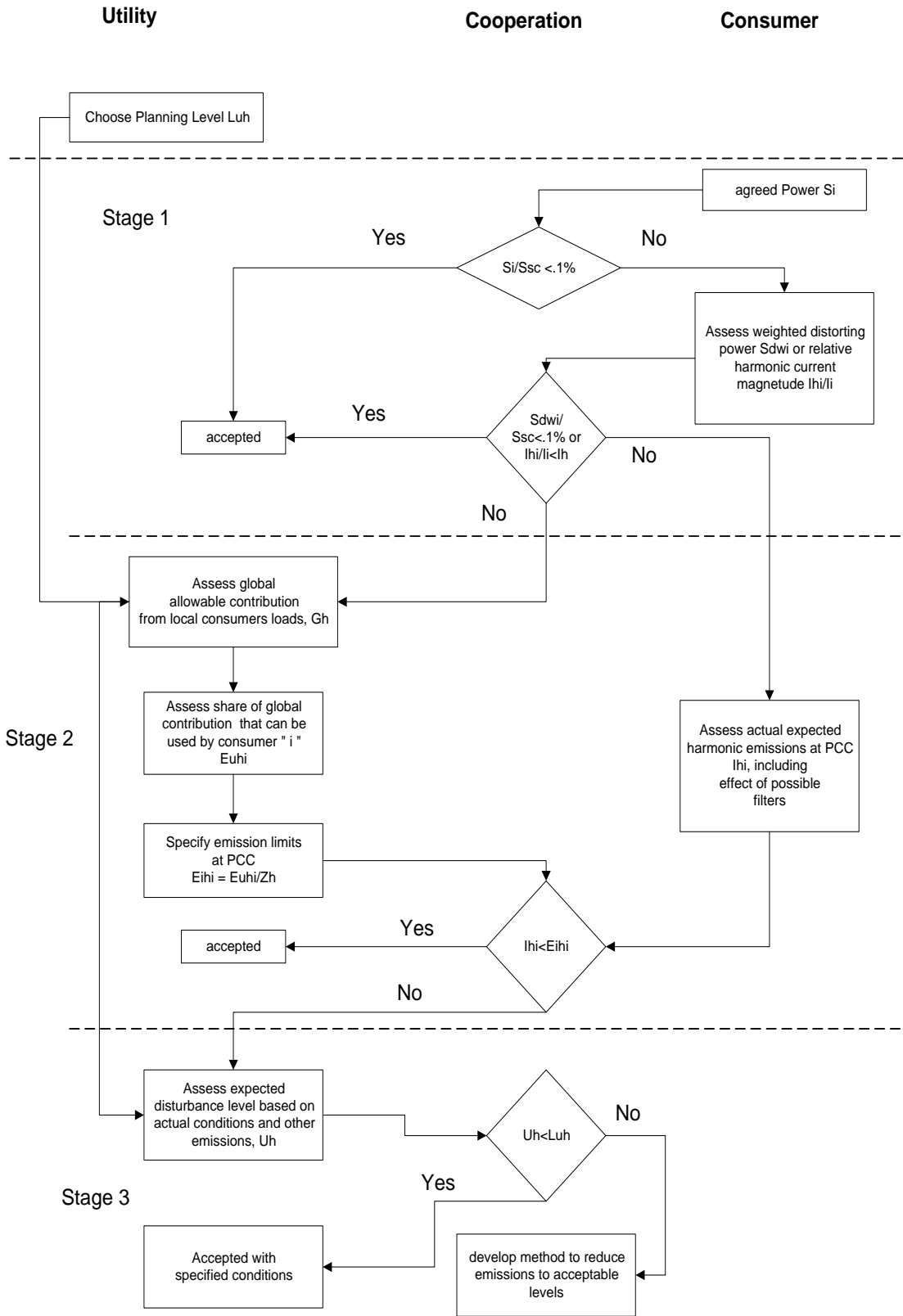


Figure 4.0 Evaluation Procedure for MV Consumers

The first criteria tends to cover the load where  $S_i$  may be 100% non-linear. The second criteria impose a minimum injection level (without doing extensive studies) that has been found to be reasonable based upon experience provided the load is less than 500 KVA and relatively few in numbers. It is generally assumed the non linear load has no passive filters at this stage as may be the case of  $S_{Dwi}$  being a small percentage of  $S_i$ .

**Stage 2** assesses how the harmonic absorption capacity of the feeder shall be utilized by the new and existing consumers. This approach works well if the load development of the feeder is known, for example multiple padsites in an oilfield. ATCO Electric can perform the necessary studies to allocate the absorption capacity of the feeder. Some new terms:

- $L_{uh}$  Planning Level (harmonic voltage)
- $E_{uhi}$  Consumer's allocation of harmonic voltage at PCC
- $E_{ihi}$  Consumer's emission limit (harmonic current) at the PCC
- $U_h$  Harmonic voltage level based upon actual conditions at the PCC

When the development is unpredictable, a first come first serve approach has historically been adopted but some type of allocation is warranted. In this situation the applied criteria becomes:

$$\frac{I_{hi}}{I_i} < I_h = E_{ihi} \quad (\text{Table 11.0 Emission Limits})$$

This prevents the first Consumer from monopolizing the absorption capacity. Inherent in these criteria is the assumption that the existing absorption capacity exceeds the distorting power of any new load. As feeder development continues, the more rigorous approach requiring ATCO Electric to specify limits,  $E_{ihi}$  may eventually arise.

**Stage 3** criteria deals with the failure to comply with  $E_{ihi}$  limits. In this situation, the overall criteria come down to comparison with the planning level for voltage distortion:

$$U_h < L_{uh} \quad \text{After the new load has been commissioned}$$

If exceeded, a method is needed to reduce emissions to acceptable levels.

As the system is capable of a certain degree of harmonic current absorption without exceeding voltage distortion levels, this allocation of absorption capacity will be controlled by ATCO Electric. The calculation procedures are detailed in CAN/CSA C61000 3-6:04.

If a Consumer has multiple sites in an area, ATCO Electric may implement a pseudo 12 pulse cancellation scheme using alternating Delta and Wye primary connected transformers. The limits in Table 11.0 would have to be adjusted to reflect cancellation of the 5<sup>th</sup> and 7<sup>th</sup> harmonics. Installation of an area filter might be a more effective solution to reducing MV voltage distortion as opposed to individual load LV filtering. If an area filter were the adopted solution, then ATCO Electric would set  $E_{ihi}$  limits based upon individual Consumer's distorting power<sup>15</sup>.

The limits in Table 11.0 are applicable to all commercially available drives irrespective of pulse number.

Table 11.0 doesn't cover interharmonics. The limits on interharmonic voltage must comply with Section 6.6 irrespective of load level  $S_i$  at either the PCC or IPC nearest the ATCO Electric Service entrance.

In Table 11.0 there are also limits for HV systems which are generally ½ those for LV and MV systems. Under some circumstances where only a single feeder exists the interface point between HV and MV is at the substation transformer and the injection currents entering the transformer (as measured on the MV bus) cannot exceed HV limits. Note the applicable short circuit level,  $S_{sc}$  on the HV is much larger than the MV.

In Table 11.0,  $I_L$  is the maximum demand current based upon 15 minute interval or it could be Iload95% (95% value from the CPF for Load current – for 1 week)<sup>16</sup>. TDD is the Total Demand Distortion that is calculated the same as DF but uses  $I_L$  for normalization.<sup>17</sup>

ATCO Electric must be notified if harmonic load is being added to an existing utility transformer. If the calculated harmonic current is in excess of 5% of the ATCO Electric transformer's rated current as defined in IEEE C57.12.00-1987, the transformer will have to be changed. The incremental costs associated with the transformer change as assessed by ATCO Electric's Consumer Representative will be charged to the Consumer.

To achieve compliance, the current injection limits cannot be exceeded per Section 5.3.

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<sup>15</sup> The intent is to filter the multiple small VFD loads and not the large loads (> 750 KVA). The larger loads will have prescribed emission limits.

<sup>16</sup> Provided the normal weekly load cycle being established

<sup>17</sup> Where  $I_L \ll I_i$ , i.e. load hasn't yet materialized, TDD will be based on  $I_i$ . The expectation is  $I_L \approx I_i$  but there may be special conditions in effect (**Stage 3** of *Figure 4.0*).

$I_{sc}/I_L$	<11	10<h<17	16<h<23	22<h<35	34<h	TDD
Current Distortion Limits for 120V through 69 KV						
<20*	4.0	2.0	1.5	0.6	.3	5.0
20<50	7.0	3.5	2.2	1.0	.5	8.0
50<100	10.0	4.5	4.0	1.5	.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
Current Distortion Limits for 72 KV through 144 KV						
<20*	2.0	1.0	0.75	0.3	0.15	2.5
20<50	3.5	1.75	1.25	0.5	0.25	4.
50<100	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
Current Distortion Limits for 240 KV						
<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

Notes:

1. Even harmonics are limited to 25% of the odd harmonic limits above.
2. Current distortions that result in a dc offset, e.g. half-wave converters are not allowed.
3. \*All power generation equipment is limited to these values of current distortion, regardless of actual  $I_{sc}/I_L$ .
4.  $I_{sc}$  = maximum short circuit current at the PCC
5.  $I_L$  = maximum demand load current or Iload95% CPF from weekly load cycle (fundamental frequency component) at PCC.

**Table 11.0** Current Distortion Limits from IEEE 519 - 1992

### 6.11 Telephone Interference Limits

All Category B Consumers must ensure the residual I\*T is less than 500 and the balanced I\*T is less than 10000 at the PCC.

## **Section 7 - Responsibilities for Mitigation**

### **7.1 Mitigation of telephone interference**

When the Telephone Company, or other Consumers with telecommunication facilities, determines that interference is being caused by harmonic generation on the power network within an area, the Telecommunications Company will notify ATCO Electric. Expenses incurred for the mitigation of telephone interference will be the responsibility of the Consumer. ATCO Electric will negotiate with the Telephone Company to ensure that a number of alternatives are investigated and the lowest cost solution is implemented.

If a number of Consumers are involved in the mitigation of telephone interference, then each Consumer shall share in the mitigation cost. ATCO Electric will ensure that the least cost solution alternatives are investigated and implemented on a case to case basis. ATCO Electric reserves the right to determine the cost sharing between each Consumer.

### **7.2 Determination of limit violation and responsibilities**

When (inter)harmonic voltage concerns are raised, ATCO Electric will measure the (inter) harmonic current and (inter)voltage at various system locations to determine the emission pattern. If the agreed current emission distortion limits discussed in Section 6.10, and/or the interharmonic voltage limits from Section 6.6 are being exceeded by (inter)harmonic producing Consumer(s), and the impedance envelope given to Consumers by ATCO Electric is still within tolerances, the Consumers will be notified that they must mitigate the current distortion. If other Consumers including ATCO Electric are being negatively influenced by the excessive (inter)harmonic generation of the Consumer(s), the offending Consumer will be asked to curtail operations until mitigation equipment is in place.

In the event of voltage flicker violations, the offending Consumer(s) will be asked to curtail operations until mitigation equipment is in place.

### **7.3 Current Distortion Limits exceeded after changes to the Supply Network**

When ATCO Electric makes changes to the supply network that effectively changes the system's impedance envelope in a negative way such that the Consumer(s) equipment is now in violation, ATCO Electric will be responsible for resolving the current distortion issues at the PCC. Typically an increase in the short circuit level is an improvement and should not necessitate major changes since the harmonic absorption capability of the

system has been increased. The Consumer should specify filters capable of a small degree of re-tuning. Taps on the inductor or removal/addition of capacitors will accomplish this.

#### 7.4 Voltage Flicker Limits exceeded after changes to the Supply Network

If the short circuit capacity at the PCC is reduced due to system changes and a voltage flicker violation arises, ATCO Electric will take steps necessary to mitigate the problem.

#### 7.5 Excessive Voltage Sags on Equipment Start up

If the startup characteristics of a new load cause the 25 kV RMS voltages to violate the following limits:

- <91.6% at the PCC
- <90% anywhere else on the feeder (excluding the transmission substation)
- a voltage variation > 5% of pre-start voltage at the transmission substation

ATCO Electric shall investigate the reasons for this phenomenon. Should the root cause be due to design changes or equipment modifications in the facility not communicated to ATCO Electric and an interim operating agreement cannot be reached, ATCO Electric shall shut down the facility or part thereof until such time as repairs have been affected.

#### 7.6 Harmonic limits not exceeded

It is possible that problems may be encountered even though the harmonic current injection limits specified are not exceeded. It can arise if the expected system levels of harmonic cancellation do not materialize. ATCO Electric will make every reasonable effort to avoid such problems but under these circumstances, all parties involved, including the manufacturers and installers, will meet to determine the source of the problem. Responsibility for mitigating the problem will be determined on a case by case basis.

## **Appendix**

### A1 Glossary of Terms

The following glossary contains definitions of the more commonly used terms, and in some cases, elaboration of ATCO Electric's interpretation of the term. A good reference document is IEEE Standard 1159-1995.

#### **Background voltage harmonics**

The existing voltage distortion profile at the point of common coupling (PCC) prior to energization of the new load, ATCO Electric will attempt to benchmark the EMC environment prior to the new load addition.

#### **Capacitive Smoothing**

The application of a capacitor connected across the DC output of the converter or front end section.

#### **Commissioning**

A series of tests carried out to prove a piece of apparatus, circuitry or system will operate within its contractual tolerance levels. Usually performed prior to and during initial energization of a project. It should be noted the equipment might not be ready to go to its full output due to other restrictions. For this reason ATCO Electric will perform a compliance test once the facility has reached its steadystate loading condition.

#### **Commutation**

Refers to the natural transfer of current from one diode (thyristor) leg to another within a converter during operation which also coincides with the commutation notch

#### **Commutation Notches**

The dip in supply voltage to a converter due to the momentary "short circuit" during the commutation interval

#### **Distortion Factor**

The ratio of the root mean square of the harmonic content to the value of the fundamental quantity expressed as % of the fundamental:

$$DF = \frac{\sqrt{\sum_{n=2}^{50} IH_n^2}}{IH_1} \times 100\%$$

$I_{H_n}$  refers to the individual harmonic. Note if the fundamental is very small or non-existent, the  $DF$  factor is highly exaggerated or infinite.

**$h$ , or  $n$**

Symbolizes the order of harmonic voltage or current

**Harmonic**

The sinusoidal component of a periodic waveform having a specific magnitude and phase with a frequency that is an integral multiple of the fundamental frequency, Harmonics are sometimes referred to as the Fourier component. Any periodic waveform can be broken down to its Fourier components.

**$I_L$**

The maximum demand load current (fundamental frequency component) at the PCC. It can also be the  $I_{load95\%}$  value from the Cumulative Probability Function of load current.

**Impedance Scan**

Is sometimes called the Driving Point Impedance, this is the positive sequence system impedance seen at each harmonic frequency up to the 50<sup>th</sup> harmonic at the point of common coupling (PCC).

**Individual Harmonic Distortion (IHD)**

The RMS value of a single harmonic component expressed as a percentage of the RMS value of the fundamental:

$$\frac{IV_{rms_n}}{IV_{rms_1}} \times 100$$

In the case of harmonic voltage distortion, the nominal operating voltage shall be used as the RMS value of the fundamental frequency component. In the case of harmonic current distortion, the RMS value of the normal operating maximum (or 95<sup>th</sup> percentile) fundamental current shall be used as the fundamental component.

**Inductor for current smoothing**

Is the application of an inductive element connected in series with the positive leg of the DC output of the converter section (sometimes split into two inductors on both positive and negative legs). It can also be referred to as the DC Link reactor.

**$I_{sc}$**

Is the maximum short circuit (3 phase) current from the supply network at the PCC.

**I\*T Product**

The Inductive Influence calculated by the root sum square of the individual harmonic currents multiplied by the weighting factor (TIF) to 5000 Hz. Balanced I\*T is calculated

using positive (harmonics of order 1,4,7,10...) and negative sequence (order 2,5,8,11...) harmonics in phase conductors. Residual I\*T is calculated using zero sequence harmonics (triplen harmonics 3,6,9,12...) in the return path as well as the zero sequence component of the positive and negative sequence harmonics that flow in the return path.

### **In Plant Point of Coupling (IPC)**

A point on a network inside a system, or installation, electrically nearest a particular load at which other loads are, or could be, connected. Essentially this is a point within the consumers system. The service entrance (utilization voltage point) would be the ATCO Electric interface point. CSA/IEC standards have assigned (3) electromagnetic environment classes intended to allow the consumer to ensure EMC within his plant. Due to a number of constraints, the service entrance may be the only point available for compliance measurement. Under these conditions, the compliance limits normally specified at the PCC will be adjusted accordingly. Of note is that emission limits (currents) are not affected in this circumstance.

### **LV, MV, HV and EHV**

Classifier for system voltage,  $U_{nom}$ , per IEC standards:

- Low voltage (LV) refers to  $U_{nom} < 1 \text{ KV}$
- Medium voltage (MV) refers to  $.99 \text{ KV} < U_{nom} < 36 \text{ KV}$
- High voltage (HV) refers to  $35 \text{ KV} < U_{nom} < 231 \text{ KV}$
- Extra High voltage (EHV) refers to  $230 < U_{nom}$

The maximum ATCO Electric Transmission voltage is 275 KV which would not be considered EHV in North America; however the lower levels are inline with standard practice.

### **Non-linear load**

A load that draws a non-sinusoidal current wave when supplied by a sinusoidal voltage source, alternatively, the shape of the current waveform is different from the supply waveform. Power electronic devices typically switch in a portion of the voltage supply waveform to the DC bus; thus the current draw tends to exist only while the switched supply waveform is present.

### **Point of Common Coupling (PCC)**

The PCC is the point on the ATCO Electric system, which is common to other Consumers. This would typically be the 25 KV Bus and/or a specific point on the Feeder line to the Consumer's facility. It is the point on the system where the quality of the voltage waveform is being maintained and the harmonic emission (current) injection is being controlled.

### **Power Factor**

For harmonic environments, the power factor becomes the ratio of the real power (KW) to the total volt-ampere (KVA) of the load. This is referred to as the *True Power factor*

(*pf*) of the system. When dealing with distorted current and voltage waveforms, the distortion component makes the *True Power Factor* much lower than the *Displacement Power Factor* (where *Displacement Power Factor* is  $\cos(p_1)$  where  $p_1$  is the angle between the fundamental components of voltage and current ( $V_1$  and  $I_1$ )). As the load becomes more linear:

*True Power Factor approaches Displacement Power Factor (Linear Loads)*

### **Root Sum Square**

The root-sum-square is the square root of the total sum of the square of each component number:

$$RSS = \sqrt{a^2 + b^2 + c^2 + \dots}$$

### **Series Inductance**

For Drive applications, this will be an inductance placed prior to the front end of the converter section of the drive on the AC mains and is sometimes referred to as an AC choke. This inductance helps to lower the harmonic current distortion, reduce notching, and should also be used to avoid nuisance tripping of the drive due to utility or Consumer capacitor switching operations. A typical size is 3% based on the drive rating. A standard isolation transformer serves the same purpose.

### **Symmetrical Components**

A mathematical method developed in Power Systems engineering which was originally developed for the analysis of unbalanced faults within a 3 phase system. The approach transforms a set of unbalanced vectors (voltages, currents and impedances) into 3 sets of balanced vectors. These balanced vectors can be manipulated to calculate the fault currents for unbalanced system conditions. The transformation can also be applied to sets of unbalanced harmonic vectors<sup>18</sup>. The 3 sets are:

*Positive Sequence* – This set of vectors represents the balanced set of vectors rotating in phase sequence ABC. Under normal near ideal conditions only the positive sequence set exists in the power system. Positive sequence currents produce the proper torque within motors. For harmonic situations, this will include the fundamental plus  $h=4, 7, 10\dots (3h+1)$

*Negative sequence* - This set of vectors represents the balanced set of vectors in the phase sequence CBA. Under normal conditions, the negative sequence sets tend to be negligible in magnitude within the power system. Negative sequence currents produce a torque, which opposes the positive sequence torque in motors. For harmonic situations, this will include  $h=2, 5, 8, 11\dots (3h-1)$

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<sup>18</sup> In what follows, the harmonic sequence vectors are true only for identical waveforms phase shifted 120 and 240 degrees. In real measurements for example, the 5<sup>th</sup> harmonic could have zero, positive and negative sequence components.

*Zero sequence* – This set of vectors represents 3 in phase vectors that are equal in magnitude. They represent the residual (vector sum of the 3 phase components). Under normal ideal conditions, zero sequence sets tend to be negligible in magnitude within the power system. Zero sequence currents produce no useful torque within motors. Because they are unidirectional, they tend to flow in the ground/neutral circuit of the power system. For harmonic situations, this will include  $h=3, 6, 9\dots (3h)$

### **System or Mains**

For this document refers to the source of supply to the point of common coupling.

### **True RMS**

True RMS = Root Mean Square. This is the value of a current or voltage waveform given by the following formula:

$$RMS = \frac{1}{T} \sqrt{\int_0^T V(t)^2 dt}$$

$T$  is the period of the waveform. If a measurement instrument does not have True RMS stamped on it, it does not accurately account for the harmonic distortion of the waveform and will give incorrect values.

### **Total Demand Distortion (TDD)**

The TDD is the total Root Sum Square (RSS) of the harmonic current expressed in % of the nominal maximum demand load current. (IEEE 519)

### **Total Harmonic Distortion (THD)**

See Distortion Factor (DF).

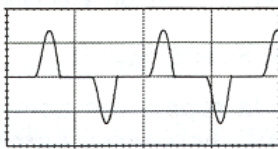
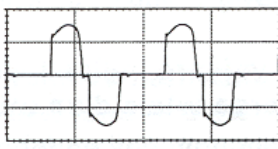
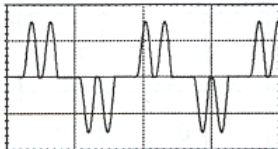
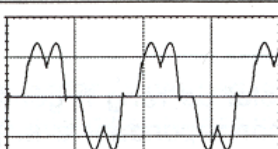
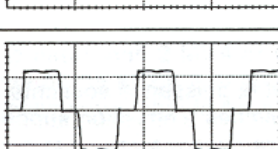
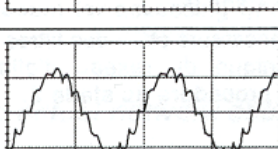
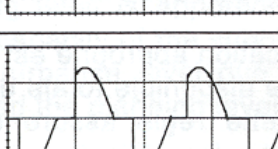
### **Total Plant Load**

The total demand load of the facility in MVA without any co-generation capacity, the total plant load should incorporate load diversity factors to accurately reflect the anticipated plant load profile during design stages.

### **VFD, ASD, VSD**

Acronyms for power electronics technology applied to speed/torque control of induction motors. VFD stands for Variable Frequency Drive, ASD (Adjustable Speed Drive), VSD (Variable Speed Drive). There is no standard usage.

## A2 Non-linear Loading Factors (IEC 1000 3-6)

Typical equipment connected to LV, MV or HV	Typical current waveform	Typical THD	Weighting Factor ( $W_j$ )
Single phase power supply (rectifier and smoothing capacitor)		80 % (high 3rd)	2,5
Semiconverter		High 2nd,3rd, 4th at partial loads	2,5
6-pulse converter, capacitive smoothing, no series inductance		80 %	2,0
6-pulse converter, capacitive smoothing with series inductance > 3%, or d.c. drive		40 %	1,0
6-pulse converter with large inductor for current smoothing		28 %	0,8
12-pulse converter		15 %	0,5
AC voltage regulator		Varies with firing angle	0,7

### A3 Example of Category Selection

During initial Consumer contact, ATCO Electric is informed that a new non-linear load will be added to an existing plant. The following details are given:

- The total plant load (with existing and new load considered) will be  $S_i = 6$  MVA
- Non-linear loads:
  - Existing: 4 X 50 Hp 6 pulse VFDs with only capacitive smoothing
  - New:
    - 4 X 50 Hp 6 pulse VFDs with capacitive smoothing and a series inductance greater than 3%
    - 2 X 2500 Hp 6 pulse VFDs with capacitive smoothing and a series inductance greater than 3%
- There is 400 kVAR installed capacitance existing at a single location on the plant bus.
- Consumer is served by dedicated 25-4.16 kV stepdown transformer

#### *Criteria 1 Determination*

The PCC is the 25 kV bus.

Using Table A2 for the non-linear load weighting factors, the weighted harmonic loading at this plant is:

$$S_{Dwi} = [(4 \times 50) \times 2.0 + (4 \times 50) \times 1.0 + (2 \times 2500) \times 1.0] \times 0.746 \text{ KW} / \text{Hp} = 4180 \text{ KW}$$

The system fault level at the PCC is 100 MVA thus:

$$\frac{S_{Dwi}}{S_{sc}} = \frac{4.180 \text{ MW}}{100 \text{ MVA}} \times 100 = 4.18\% > 1\% \quad \textbf{Exceeds Criteria}$$

#### *Criteria 2 Determination*

$$\frac{S_{Dwi}}{S_i} = \frac{4.180 \text{ MW}}{6 \text{ MVA}} \times 100 = 69.7\% > 10\% \quad \textbf{Exceeds Criteria}$$

#### *Criteria 3 Determination*

All the capacitance is installed in one location so the estimated harmonic resonance point may be determined by using the following formula on the utilization bus (4.16 kV):

$$H_{resonance} = \sqrt{\frac{MVA_{ShortCircuit}}{MVA_{capacitor}}}$$

Note that  $MVA_{ShortCircuit}$  is the fault MVA at the capacitor bank location on the utilization bus.

This determination is very approximate since it ignores the background voltage distortion level. Its main use is to rule out tuning a capacitor to a characteristic VFD harmonic. The addition of a capacitor will change the driving point impedances of the supply system at all harmonic frequencies. In more complex cases, ATCO Electric will analyze the impact of the capacitors on the supply system.

In this particular case:

$$MVA_{ShortCircuit} = 12.0MVA$$

$$H_{resonance} = \sqrt{\frac{MVA_{ShortCircuit}}{MVA_{capacitor}}} = \sqrt{\frac{12}{.4}} = 5.48$$

Giving:

$$|H_{resonance} - 5| = |5.48 - 5| = .48 > .35 \quad \text{Meets Criteria}$$

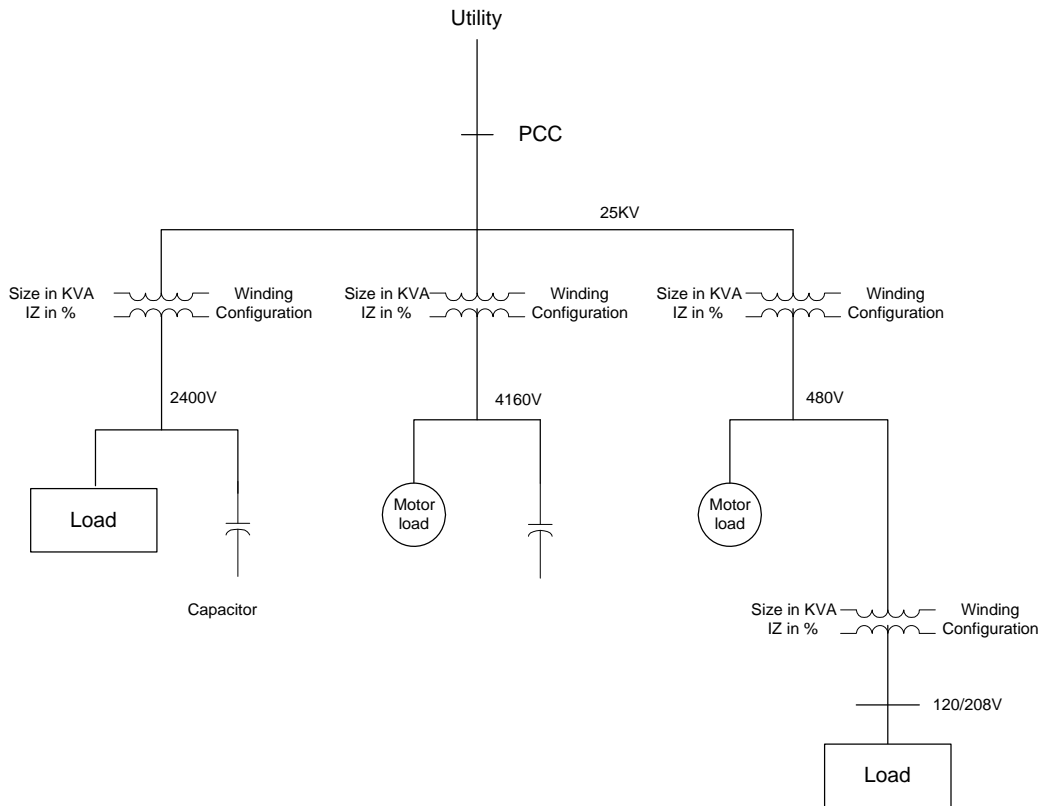
$$|H_{resonance} - 6| = |5.48 - 6| = .52 > 0.1 \quad \text{Meets Criteria}$$

In general any shunt capacitor in a harmonic environment should be detuned with a series reactor. It should be noted that a passive filter will have a parallel resonance at some lower non harmonic frequency. If this frequency matches an interharmonic frequency generated by the Drive(s) this filter could be much stressed.

### Summary

For this example, all the criteria were calculated. The Consumer did not meet Criteria 1 and 2; consequently this project did not qualify for Category A classification. The Consumer must follow Category B procedure. An impedance scan from ATCO Electric should be obtained and actual expected harmonic emissions  $I_{hi}$  should be assessed. ATCO Electric (upon receipt of the necessary information) shall specify the  $E_{ihi}$  levels. The specification for active or passive filters or selection of a higher pulse number for the Drive might be design options pursued to meet the emission limits.

## A4 Plant Single Line Diagram



Legend: The following information is necessary from the Consumer

### Motor Load

All Motors greater than 10 Hp will be identified separately showing Hp and Starting type. VFDs will have the following additional information: size, pulse number, AC or DC inductance size, smoothing capacitor size.

### Load

All non motor loads, these loads are to be totaled and identified as linear or non-linear.

### Capacitors (Caps.)

All capacitors will be identified separately, including surge, power factor correction and filter capacitors showing VARs or microfarads, inductances (for filters), damping resistors (filters) and nameplate voltage rating.

### Transformers

All non-utility transformers will have the following information: size (KVA), number of windings, impedances (%) between windings, and each voltage winding configuration (delta or Wye or other).