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REVISIONS: UPDATED LEGAL ACKNOWLEDGEMENT FORM. FD MAR '16

DESIGNED J. AGNOLIN	RECOMMENDED  F. DENNERT	ACCEPTED  G. REIMER	ENGINEER OF RECORD 	NOTICE FROM THE EXECUTIVE VICE PRESIDENT TRANSMISSION AND DISTRIBUTION AND CUSTOMER SERVICE	
DISTRIBUTION STANDARDS 		ISSUED: MAR 2016 REPLACES: MAY 2004 ORIGINALLY ISSUED: NOV 1980		PAGE 1 OF 2	ES43/53/54/55/65 A1-01.01
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Scope

This manual is one of a series containing standards for construction of the BC Hydro electrical distribution plant within the service area of BC Hydro. A new distribution plant shall be designed, constructed, owned, operated, maintained and repaired to these standards.

Purpose of Standards

BC Hydro objectives require standardization to:

- a) Ensure uniform safety requirements comply with BC statutes and regulations.
- b) Provide uniform system reliability.
- c) Provide uniform operating practices.
- d) Permit economic bulk purchasing of materials.
- e) Achieve optimum life cycle cost of plant construction.
- f) Effect efficient quality assurance.

Responsibility

The Distribution Standards Department prepares these standards and verifies that specified plant and procedures will perform adequately under all normally expected conditions encountered throughout the province of British Columbia. These standards are approved by Professional Engineers. It is the responsibility of BC Hydro Managers to ensure that the standards are followed unless abnormal conditions are encountered that require variations. These variations should be kept to a minimum and their performance shall be the responsibility of the Professional of Record in charge of the project, who will record and seal the variation based on satisfactory qualifications and experience to do so. As per the latest revision of the BC Hydro Distribution Owner's Engineer Guide, these variations must be accepted by BC Hydro's Owner's Engineer.

Use of Stock Materials

The electrical distribution plant covered by these standards is built using stock materials approved by a Professional Engineer as required by law. The use of non-stock materials for special and unusual situations must be approved by Distribution Standards or the BC Hydro Engineer responsible for the project.

Revisions to Manual

These standards are revised from time to time to improve the safety, performance, workability, cost effectiveness or appearance of the plant. The existing plant built to previous standards need not be updated unless so specifically advised by BC Hydro. When maintenance or other work, such as voltage conversion or conductor change is being done, updating plant to current standards is encouraged.

Mailing Addresses

The manual has been issued to a corporation or firm rather than to an individual. The corporation or firm is responsible for the safekeeping of the manual, and for keeping it current. Changes of address or in number of copies required must be reported promptly.

Suggestions for changes in the manual, or required changes of address may be made on the pre-addressed comment sheet included in the Manual and with each issue of revision.

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ES55 Design Standards

Q4-09 – Current Harmonics

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Revision History

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 S.C. MERRIMAN # 38599 BRITISH COLUMBIA PROFESSIONAL ENGINEER	RECOMMENDED  K. MIDDLETON	ACCEPTED  F. DENNERT	MEDIUM-VOLTAGE CUSTOMER EMISSION LIMITS CURRENT HARMONICS		
DISTRIBUTION STANDARDS 			ENGINEERING STANDARD		
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Scope

This standard defines the method for determining harmonic emission limits for customers connected to, or requesting connection to BC Hydro's public medium-voltage (MV) distribution network. It also describes the assessment process for verifying compliance with prescribed harmonic emission limits.

Definitions

These terms are used in this section:

Term	Definition
Harmonic	Sinusoidal component of a complex wave whose frequency is an integer multiple of the fundamental frequency.
Harmonic Order	Ratio of the frequency of any sinusoidal component to the fundamental frequency. A component of order n (with $n > 1$) is generally designated ' n^{th} ' harmonic.
Total Harmonic Distortion (THD)	The ratio of the r.m.s. value of the harmonic content of a periodic voltage waveform to the r.m.s. value of the fundamental component.
Total Harmonic Current (THC)	The ratio of the r.m.s. value of the harmonic content of a periodic current waveform to the r.m.s. value of the fundamental component.
Public Network	Low or medium voltage networks are considered 'public' when they serve, or are intended to serve, more than one customer from the same transformer.
Private Network	Low or medium voltage networks are considered 'private' when they serve, and are only intended to serve, one customer from a dedicated transformer.
Electromagnetic Disturbance	Any electrical or magnetic characteristic, either conducted or radiated, that affects the normal operation of equipment, or causes unwanted sensory experiences for people.
Emission Level	The level of a given electromagnetic disturbance emitted from a particular device, equipment or system
Medium Voltage (MV)	Describes networks with a rated voltage of $1,000 \text{ V} < U_n \leq 35,000 \text{ V}$.
Cumulative Probability (CP[x])	The probability that the measured variable falls within a specified range [x]. For instance, the CP95 value for a set of voltage measurements refers to the voltage quantity that was not exceeded during 95% of the recorded period. Refer to Q1-02 for details.

Application

Q4 is intended for application by distribution planning engineers, regional engineers, designers and power quality engineers for:

- 1) Calculation of customer emission limits for approved operation on a BC Hydro-owned public MV network, and
- 2) Assessment of customer emission performance for confirmation of operational compliance with prescribed limits.

Q4 emission limit determination is valid for all customers connected to, or requesting connection to, a BC Hydro-owned public MV network.

Q4-09 specifically defines BC Hydro's emission limit requirements for current harmonics.

What are Current Harmonics?

Harmonics are frequency components of a periodic waveform with integer multiples of the fundamental frequency; they exist in both voltage and current waveforms. Current harmonics are the responsibility of the customer to control, while BC Hydro is responsible for control of voltage harmonics. Current harmonics are emitted to the power network by customer non-linear loads such as: electronic equipment, ballasted lighting, saturated transformers, inverters and drives.

The purpose of harmonic emission limits is to ensure that that planning limits for voltage harmonics are not exceeded on the BC Hydro network.

Typical Causes

Voltage harmonic distortion is the cumulative effect of operating many non-linear loads on the power system. The harmonic current drawn by these loads flows through the impedance of the power system and results in harmonic voltages. It follows that higher harmonic currents and higher impedances lead to higher levels of voltage harmonic distortion. Common sources of harmonic currents on the power system are:

- switched-mode power supplies (consumer electronics);
- AC and DC motor drives;
- ballasted lighting (fluorescent, HID, etc.), and
- electric arc furnaces.

Effects

One of the common impacts of harmonics is heating of motors, transformers, and cables. Skin effect, eddy currents and hysteresis losses all contribute to excessive heating, some of which increase with the square of the frequency. For this reason, de-rating of equipment may be required to avoid failure due to thermal overloads.

Another problem associated with harmonics is overvoltage or poor voltage regulation due to resonance. If the electrical system resonates near a harmonic frequency, excessive harmonic voltage and current can result. Customer and/or utility capacitor banks can act as sinks for harmonic currents and can become overloaded when doing so. This frequently results in blowing of fuses. It is estimated that as many as 50% of the capacitor banks on the distribution network are impacted by this phenomenon.

Triplen harmonic currents are also of concern on the distribution system as they are additive on the neutral. An undersized neutral conductor, either on the utility system or in a customer facility, can suffer from thermal overload, voltage rise or excessive voltage distortion. High Neutral-to-Earth voltage can result in nuisance shocking for people, or reduced production for dairy farms due to animal discomfort.

Lastly, interference on communications circuits is another problem related to harmonic currents on the power distribution system. Telephone interference can result when the power system conductors run parallel to copper telephone conductors in rural service areas where analog communications are used.

MV Customer Emission Limits

Harmonic emission limits on BC Hydro's public MV network are allocated such that overall network performance complies with planning limits defined in ES55 Q2-09.

All customers connected to, or applying for connection to, BC Hydro's public MV network are subject to harmonic emission limits at their point of common coupling (PCC).

This section describes the method for allocating emission limits to customers; sample MV-customer calculations are conducted in ES55 Q5-02 for further clarification.

Step 1: Simplified Evaluation for Immediate Approval**Agreed Power**

The first simplified evaluation method compares the agreed apparent power (S_i) of the installation with the short circuit power (S_{sc}) available at the proposed or existing PCC:

$$\frac{S_i}{S_{sc}} \leq 0.2\% \quad (\text{EQ 1})$$

- 1) Details about determining a customer's agreed power can be found in ES55 Q1-04.
- 2) Details about calculation of available short circuit power can be found in ES55 Q1-01.

If the above condition is satisfied then the customer is approved for connection without further assessment.

Weighted Distorting Power

If the agreed power criterion is not met, a second simplified approach is used to assess only the distorting equipment. The size and type of each piece of equipment is required; then the weighted distortion power can be calculated as follows:

$$S_{DWi} = \sum_j D_{Dj} \cdot W_j \quad (\text{EQ 2})$$

S_{Dj} Apparent power of each distorting equipment, j , in the facility, i .

W_j Weighting factor for the type of equipment (Table 1)

Table 1 - Weighting Factors W_i

Typical Equipment Connected to LV or MV	Typical Current THD	Weighting Factor (W_i)
Single-phase power supply	80%	2.5
Semi-converter	High 2 nd , 3 rd , and 4 th at partial loads	2.5
6-pulse convertor (no series inductance)	80%	2.0
6-pulse converter (series inductance > 3%, or DC drive)	40%	1.0
6-pulse converter (large inductor)	28%	0.8
AC voltage regulator	Varies with firing angle	0.7
12-pulse converter	15%	0.5

The weighted distortion power is then compared to the short circuit power available at the proposed or existing PCC:

$$\frac{S_{DWi}}{S_{SC}} \leq 0.2\% \quad (\text{EQ } 3)$$

If the above criterion is met then the customer may connect without further assessment.

Stage 2: Individual Emission Limits

If the criteria in Step 1 are not satisfied, then the individual customer emission limits must be determined. The approach used here allocates current emission limits such that the planning levels at the MV busbar in the substation and out on the feeders will not be exceeded. Consideration is made for the absorption capability on longer distribution circuits as well as cancellation that occurs due to varying phase angles of harmonics. The summation law exponent accounts for this phase angle variation.

Summation Law Exponent

The following summation law exponents (α) are used in subsequent calculations; they are defined by harmonic order.

Table 2 - Summation Law Exponent (α)

Harmonic order	α
$h < 5$	1
$5 \leq h \leq 10$	1.4
$h > 10$	2

Impedance Values

The reactive impedance of the system will increase linearly with the harmonic order as defined here:

$$x_h = x \cdot h \quad (\text{EQ } 4)$$

For all emission limit calculations, this impedance must be assessed as per unit on a 1 MVA base.

In a balanced system, individual harmonics exist as a single sequence component (Table 3). It follows that the corresponding sequence impedances should be used for evaluation of each harmonic.

Table 3 – Balanced Harmonic Sequences

Sequence	Equation	Examples
Positive	$h = 1 + 3n$	1,4,7,10,13,...
Negative	$h = 2 + 3n$	2,5,8,11,14,...
Zero	$h = 3n$	3,6,9,12,15,...

Global Harmonic Voltage Allowance

The first step is to determine the harmonic voltage allowance for all MV installations at substation bus (%).

$$G_{hMV} = \sqrt[\alpha]{L_{hMV}^{\alpha} - (T_{hUM} \cdot L_{hUS})^{\alpha}} \quad (\text{EQ } 5)$$

L_{hMV} MV Planning limit for harmonic h

L_{hUS} Upstream planning limit for harmonic h .
Typically this will be the HV limits.

T_{hUM} Transfer coefficient from the upstream system
to the MV system under consideration. 0.5 is
used for BC Hydro's assessment.

Based on the voltage harmonic planning limits in ES55 Q2-09 and indicative HV planning limits in CAN/CSA-C61000-3-6-09, G_{hMV} is calculated in Table 4 below.

Table 4 - Global Harmonic Voltage Allowance (G_{hMV})

Odd Harmonics Non-triplen		Odd Harmonics triplen		Even Harmonics	
Order h	Harmonic Voltage %	Order h	Harmonic Voltage %	Order h	Harmonic Voltage %
5	4.62	3	3.00	2	1.10
7	3.58	9	0.94	4	0.60
11	2.90	15	0.26	6	0.40
13	2.38	21	0.20	8	0.40
17	1.78	27	0.20	10	0.38
19	1.59	33	0.20	12	0.40
23	1.31			14	0.37
25	1.20			16	0.35
29	1.03			≥ 18	0.20
31	0.97				

Allocation Constant for MV Installations

Next, the allocation constant is determined based on the characteristics of the substation and connected feeders.

$$A_{hMV} = \frac{G_{hMV}}{\sqrt{x_h}^{\alpha} \sqrt{S_{MVw} \cdot F_w^{0.33\alpha} + S_{MVn} \cdot F_a^{-0.3\alpha}}} \quad (\text{EQ } 6)$$

x_h Bus reactance at harmonic h
(p.u. on 1MVA base)

S_{MVw} MV load connected to the weakest feeder
(p.u. on 1MVA base)

S_{MVn} MV load connected to the remaining n feeders
(p.u. on 1MVA base)

F_w Ratio of short-circuit power from the sending
end to remote end of the weakest feeder

F_a Average of the ratio of short-circuit power at
the sending end to the remote end for the
remaining feeders

Note: When determining S_{MVw} and S_{MVn} , use the actual load and not the connected load size.

Note: The allocation is performed based on the normal operating condition at the substation. If multiple buses are operating in parallel then one allocation is performed. If multiple buses are operating independently then a separate allocation is performed for each.

Allocated Emission Current

Current allocation for the specific customer at each harmonic is then determined using the following formula:

$$E_{Ihi} = \frac{A_{hMV} \cdot S_i^{(1/\alpha)}}{\sqrt{hx_{ih}}} \quad (\text{EQ } 7)$$

x_{ih} reactance at harmonic h for customer location i .
(p.u. on 1 MVA base)

Performance Criteria

Customer Emission Assessment

Current harmonic measurements shall be made using the Class A method specified in CAN/CSA-C61000-4-30. A minimum measurement period of one week is required. Some portion of the period should include the expected maximum harmonic levels. The following statistical criteria are used for assessment of recorded data:

- the CP95 weekly probability values for individual current harmonics over 10-minute intervals shall not exceed the emission limits derived for the customer.
- the CP99 daily probability values for individual current harmonics over 3-second intervals shall not exceed the customer emission limits times the factor k_{hvs} .

Meter Specifications

To determine compliance with current harmonic requirements, measurements must be obtained using a power quality meter with a Class A performance as defined by CAN/CSA 61000-4-30.

Customer Response

When a customer's operation violates prescribed emission limits on the BC Hydro system, mitigation must occur within 60 days of notification.

Where mitigation requires a complex engineered solution, an extension of time may be granted, at BC Hydro's discretion, up to 90 days to allow for design, procurement, and commissioning of new equipment and/or process.

BC Hydro Power Quality Engineers are available to assist with standards interpretation, data collection and analysis, and compliance evaluation:

- They may, where applicable, offer general advice relating to potential mitigation options.
- They will not make recommendations of a specific nature for any customer facility.

Customers should act solely on advice from qualified professional electrical engineers, who are hired by the customer, when mitigation is required at their facility.

BC Hydro Response

When a customer's operation violates prescribed emission limits, BC Hydro will notify the customer of their violation. Written notification may be communicated via electronic or regular mail, and the notice will be clear that the customer's use of electricity is causing a disturbance to the BC Hydro electrical system. Where previous communication has been established electronically between BC Hydro and the customer, email notification shall be considered suitable written notification.

The written notice to the customer should outline that if a customer fails to meet emission limit requirements within the approved timeframe, then BC Hydro may disconnect the customer from the public network to prevent further disturbing operation. Where upgrades can be installed on the BC Hydro network to mitigate the disturbance, BC Hydro can offer to install such upgrades at the customer's cost. The customer's written confirmation for assuming responsibility of these costs should be obtained before installing upgrades for the benefit of the customer.

References

- ES55 Q1-04 Customer Apparent Power Assessment
- ES55 Q2-09 Network Planning Limits – Voltage Harmonics

Sources

- Neilson, J.B., Buchholz, Vern L. BC Hydro Power Quality Guide. (2005).
- CAN/CSA-C61000-2-2-04 Electromagnetic compatibility (EMC) - Part 2-2: Environment – Compatibility levels for low frequency conducted disturbances and signalling in public low-voltage power supply systems.
- CAN/CSA-C61000-3-6-09 Electromagnetic compatibility (EMC) - Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems.
- CAN/CSA-C61000-4-30-10 Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods.