# Aurora Energy Limited

Rural Network - Harmonic Standard (NS5.5)

Version: 1
Final: 10/09/2012

**Status and Application of these Requirements**

All connections on the Aurora electrical distribution network (the Network) are subject to the contractual terms of a Use-of-System Agreement which, among other things, require all consumers covered by the agreement to comply with Aurora's network connection standards. Accordingly, this document defines the requirements that must be complied with, on a continuing basis, at rural consumer installations that may inject harmonic disturbances into the Network.

These requirements will be amended periodically, to reflect changes required for continued compliance with legislation and good industry practice. It is the responsibility of installation owners to ensure that compliance with these requirements is maintained at all times. The current version of these requirements will be maintained on Aurora's website (www.auroraenergy.co.nz), and will apply from the date of publication.

**Acknowledgement**

This standard is based on the rural harmonics standard and associated processes developed by Electricity Ashburton Limited. Aurora wishes to thank Electricity Ashburton Limited for permission to use their standard as the basis for this standard.

| Version Control | | | |
|---|---|---|---|
| **Version** | **Date** | **Summary of Significant Amendments** | **Approved** |
| 1 | 10/09/2012 | Final | Mat O'Neill |

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## 1. PURPOSE AND SCOPE OF THIS DOCUMENT

As required by Aurora Energy Limited's (Aurora) Network Connection Requirements (NS5.1) policy, this document defines the requirements that must be complied with, on a continuing basis, at rural consumer installations that may inject harmonic disturbances into Aurora's electrical distribution network (the Network).

These requirements will be amended periodically, to reflect changes required for continued compliance with legislation and good industry practice. It is the responsibility of installation owners to ensure that compliance with these requirements is maintained at all times. The current version of these requirements will be published on Aurora's website (www.auroraenergy.co.nz), and will apply from the date of publication.

This standard defines the harmonic current and voltage limit requirements of harmonic producing loads. The focus of the document is on 6 pulse variable speed drives but the limits can be applied to other types of loads as well.

A consumer who wishes to connect new variable speed drives or who wishes to replace/upgrade variable speed drives (VSD) is required to comply with the guidelines provided in this document.

Existing notifiable VSD load supplied from the same transformer will be exempt from measurement provided that details of the existing drives and filters are provided using Form 3.

Consumers who wish to use existing drives, or wish to install new drives on the Network should also note the requirements of clause 31 of the Electricity (Safety) Regulations 2010.

## 2. DEFINITIONS AND ABBREVIATIONS

| | |
|---|---|
| **Characteristic Harmonic:** | The harmonic produced by the equipment in the course of its normal operation. For example, the characteristic harmonics of a six pulse VSD are- 5th, 7th, 11th, 13th etc. The characteristic harmonics are derived using the following equation-<br>$h=kq\pm1$ *Where k = any integer*<br>*q = pulse number of converter* |
| **Displacement Power Factor ($PF_{dp}$)** | The power factor at the fundamental frequency only; $PF_{dp}$ does not include any harmonic power components.<br>$PF_{dp} = \frac{kW_1}{kVA_1}$ |
| **Distortion** | The deviation of 50 Hz sine wave due to harmonic components |
| **Distortion Factor** | See: Total Harmonic Distortion (THD) |
| **Distortion Power Factor ($PF_{dt}$)** | $= \frac{1}{\sqrt{1+THD_i^2}} = \frac{I_{1,rms}}{I_{rms}}$<br>*where $I_1$ is fundamental component of current; assumes undistorted supply voltage* |

| | |
|---|---|
| **Fundamental Component** | Component whose frequency is the fundamental frequency |
| **Fundamental Frequency** | The nominal power system frequency (50 Hz) |
| **Harmonics** | The sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. For example, 5th harmonic frequency has 5 times the fundamental frequency i.e. 250 Hz. |
| **Maximum Load Current ($I_L$)** | The maximum current drawn by the load as defined in equation 2. |
| **Non-linear load** | Load that draws a non-sinusoidal current wave when supplied by a sinusoidal voltage source. |
| **NZECP** | New Zealand Electrical Code of Practice. |
| **Point of common coupling (PCC):** | The point in the Network, electrically nearest to the consumer, at which other consumers are or may be connected. |
| **Power Factor (True) (PF)** | The ratio of real power consumed to apparent power drawn (W/VA). $$PF = \frac{kW}{kVA} = PF_{dp}PF_{dt} = PF_{dp}\frac{I_{1,rms}}{I_{rms}}$$ where $I_1$ is fundamental component of current; assumes undistorted supply voltage |
| **Pulse number (q):** | The number of pulses occurring within the converter dc output during each cycle of the ac input voltage. |
| **Rural Areas** | As defined in the District Plans of the Dunedin City Council, the Queenstown Lakes District Council, and the Central Otago District Council. |
| **Short circuit current ($I_{sc}$)** | The maximum short circuit current available at the transformer secondary determined by the transformer rated kVA and the per unit impedance of the transformer at its rated kVA. |
| **Short circuit ratio ($I_{sc}$/ $I_L$)** | The ratio of available short circuit current at the point of common coupling (PCC) and the maximum load current. |

| | |
|---|---|
| **Test Point** | For dedicated harmonic load (supplied by one transformer), it is the nearest supply connection point to the harmonic mitigating equipment. For multiple harmonic loads (supplied by one transformer), it is the secondary of the supply transformer or a convenient point where harmonics compliance tests can be done. |
| **Total Demand Distortion (TDD)** | The total root mean square harmonic current distortion, in percent of the maximum load current (either 15 or 30 minute demand as available) |
| **Total Harmonic Distortion-Current ($THD_i$)** | The square root of the sum of the squares of the root mean square (rms) values of harmonic currents ($I_n$), divided by the rms value of the fundamental current ($I_1$). $$THD_i = \sqrt{\sum_{n=2}^{50} \left(\frac{I_n}{I_1}\right)^2}$$ |
| **Total Harmonic Distortion-Voltage ($THD_v$):** | The square root of the sum of the squares of the root mean square (rms) values of harmonic voltages ($V_n$), divided by the rms value of the fundamental voltage ($V_1$). $$THD_v = \sqrt{\sum_{n=2}^{50} \left(\frac{V_n}{V_1}\right)^2}$$ |
| **Voltage Unbalance Factor (VUF)** | The negative sequence voltage imbalance, and is the ratio of the negative to positive sequence component. $$VUF = \frac{V_N}{V_P} \qquad \beta = \frac{{V_{ab}}^4 + {V_{bc}}^4 + {V_{ca}}^4}{({V_{ab}}^2 + {V_{bc}}^2 + {V_{ca}}^2)^2} \qquad VUF = \sqrt{\frac{1 - \sqrt{3 - 6\beta}}{1 + \sqrt{3 - 6\beta}}}$$ |

## 3. REFERENCES


IEEE519:1992 IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.

NZECP36: 1993 New Zealand Electrical Code of Practice for Harmonic Levels (This code of practice is prepared by the Ministry of Commerce and is pursuant to the limitations of Harmonics levels Notice 1981).

Electricity Ashburton Limited - Rural Network Harmonics Standard - Electricity Ashburton Issues 2 & 3

## 4. INTRODUCTION

Harmonics are non-sinusoidal currents or voltages produced by non-linear loads. Non-linear loads such as Variable Speed Drives (VSDs), Switch Mode Power Supplies (SMPSs), electronic ballasts for fluorescent lamps, welders, etc., inject harmonic currents into the Network. These harmonic currents couple with the system impedances creating voltage distortion at various points on the Network. As a result, equipment such as computers, digital clocks, transformers, motors, cables, capacitors, electronic controls, etc., connected to the same point can suddenly malfunction or even fail completely.

As harmonics are produced by consumers' equipment, it is important that those harmonics are controlled at the consumer connection. This is considered to be a good practice, as by controlling the emission levels of individual sources of harmonics, the flow of harmonics into the network is restricted at the PCC. This will, in turn, limit widespread effects of harmonics in the entire Network.

This standard has been prepared on the basis of limits described in IEEE 519:1992. Appendix A has been included to provide sample values for typical current distortion of 1 and 3 phase converters.

## 5. HARMONIC CURRENT LIMITS

Harmonic current distortion limits are defined in Table 1, below. By limiting the harmonic injection from individual harmonic loads, unacceptable voltage distortions at the PCC can be controlled effectively for normal system characteristics. This also means that other sensitive equipment connected in the vicinity will operate free from the effects of harmonic distortion.

Table 1 sets the maximum allowable current distortions for consumers that wish to connect harmonic producing loads to the Network. These limits are applicable for six pulse drives and general distortion situations. For 12 pulse drives ($q$ = 12), the limits for the characteristics harmonics orders are increased by a factor of $\sqrt{\frac{q}{6}}$. This increase is possible if the amplitudes of the non characteristic and even harmonics are less than 25% of the limits specified in Table 1. The limits are applicable if the equipment is operating for more than one hour per day. For shorter periods (a maximum duration of one hour per day), during start-up or unusual conditions, the limits may be exceeded by up to 50%.

| **Isc/ $I_L$** | **h<11** | **11≤h<17** | **17≤h<23** | **23≤h<35** | **35≤h** | **TDD** |
|---|---|---|---|---|---|---|
| **<20*** | 4.0 | 2.0 | 1.5 | 0.6 | 0.3 | **5.0** |
| **20-50** | 7.0 | 3.5 | 2.5 | 1.0 | 0.5 | **8.0** |
| **50-100** | 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** |

**Table 1: Maximum Harmonic Current Distortion in Percent of $I_L$**

Notes:
*All power generation equipment is limited to these values of current distortion, regardless of actual short circuit ratio or $I_{SC}/I_L$.
Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.
Aurora assessment of harmonics compliance will be at full load.

The limits in Table 2 are used by Aurora to gauge harmonic voltage distortion lasting longer than one hour. For shorter periods, during start-ups or unusual conditions, these limits may be exceeded by 50%.

| Voltage at PCC | Individual Voltage Distortion (%) | Total Voltage Distortion THDv (%) |
|---|---|---|
| **Vrms≤66kV** | 3.0 | 5.0 |

**Table 2: Maximum Voltage Distortion Limits in % of nominal fundamental frequency voltage**

The value of short circuit current ($I_{sc}$) can be calculated using the following formula:

$$I_{SC} = kVA_{TF}/(Z_{pu} \times \sqrt{3} \times kV_{\emptyset-\emptyset}) \qquad \text{Equation 1}$$

Where $kVA_{TF}$ is the rated transformer kVA, $Z_{pu}$ is the per unit impedance of the transformer at rated kVA, kV is the nominal voltage i.e. 0.4kV.

The value of maximum load current ($I_L$) can be calculated using the following formula:

$$I_L = kW_{\max demand}/(PF \times MEFF \times \sqrt{3} \times kV_{\emptyset-\emptyset}) \qquad \text{Equation 2}$$

Where kV is the nominal phase to phase voltage, i.e.; 0.4kV, kW is the name plate rating of the motor, PF is the power factor at rated load and MEFF is the motor efficiency.

Note that, in most cases, Aurora's short circuit ratio ($I_{sc}/I_L$) at the PCC will fall in the range of 20-50. This means, in most cases, Aurora's TDD limit will be 8%. Equation 1 and 2 can be used to calculate the short circuit ratio and the TDD limit for a given load.

## 6. HARMONIC VOLTAGE LIMITS

If the sources of harmonic generation are restricted to the limits specified in Table 1, above, it is expected that the harmonic voltages at various nodes on the network will stay within acceptable limits, as specified in Table 2. When the harmonic voltage distortion level is greater than specified in Table 2, Aurora will conduct investigations to identify loads operating with current distortion above the specified limits, and work with consumers to ensure that they reduce THDv to an acceptable limit.

## 7. ADDITIONAL REQUIREMENTS

It is expected that consumers' contractors will take appropriate steps to maintain a high standard of installation and performance of installed equipment. All VSDs above 20 kW (combined rating of all VSDs at an installation) shall meet the requirements of this standard.

The following requirements are additional to the limits described in Table 1.

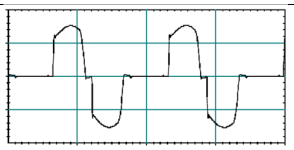
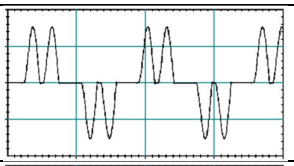
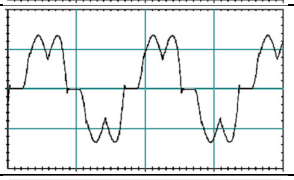
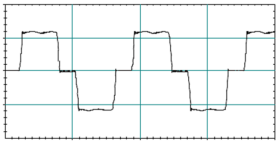
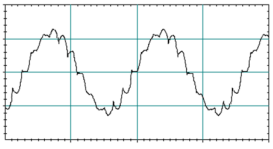
- Equipment shall not resonate with the Network.
- Equipment shall not operate with unreasonably low leading PF at reduced load. At reduced load, high leading VAr can result in supply resonances which can amplify the harmonic currents and voltages at various nodes.
- Equipment shall not interfere with Aurora's 317Hz and 1050Hz ripple signals used for tariff and load control.

- Equipment shall meet the total current harmonic distortion limits specified in Table 1 at full load, with voltage background distortion of no more than 5% and voltage unbalance of no more than 1%.
- In each case, all field tests shall be completed at the minimum background voltage distortion and unbalance. Increase in total current harmonic distortion shall be acceptable if the background voltage distortion ($THD_v$) and unbalance (VUF) is greater than 5% and 1% respectively. A re-test maybe required if compliance can't be established.
- Installation of harmonic mitigating devices in conjunction with VSDs must be planned in advance so that Aurora can properly evaluate harmonic compliance.
- On request from Aurora, harmonic performance of the equipment shall be demonstrated to show that it meets the appropriate compliance limit.

Failure to meet any part of this standard may result in either disconnection of supply or delayed connection. Aurora will only fund re-tests in instances where abnormal Network conditions have interfered with the original test.

# 8. APPENDICES

## 8.1. APPENDIX A: Typical Loads and their Harmonic Characteristics

| Type of load | Typical Current Distortion Level, THDi * | Typical Waveform | Typical Harmonic Characteristics |
|---|---|---|---|
| **Single phase converter** | 80% |  | From 3rd harmonic upwards; with no even harmonics |
| **3 phase 6 Pulse converter, capacitive smoothing, no series inductance** | 80% |  | Odd harmonics from 5th harmonic upwards; with no even or triplen harmonics |
| **3 phase 6 Pulse converter, capacitive smoothing, series inductance** | 40% |  | Odd harmonics from 5th harmonic upwards; with no even or triplen harmonics |
| **3 phase 6 Pulse converter, large inductor for smoothing current** | 28% |  | Odd harmonics from 5th harmonic upwards; with no even or triplen harmonics |
| **3 phase 12 pulse converter** | 15% |  | Odd harmonics from 11th order and upwards; with no even or triplen harmonics |

Notes:
* Residual harmonics are ignored.

## 8.2. APPENDIX B: Overview VSD Connection Procedure Process

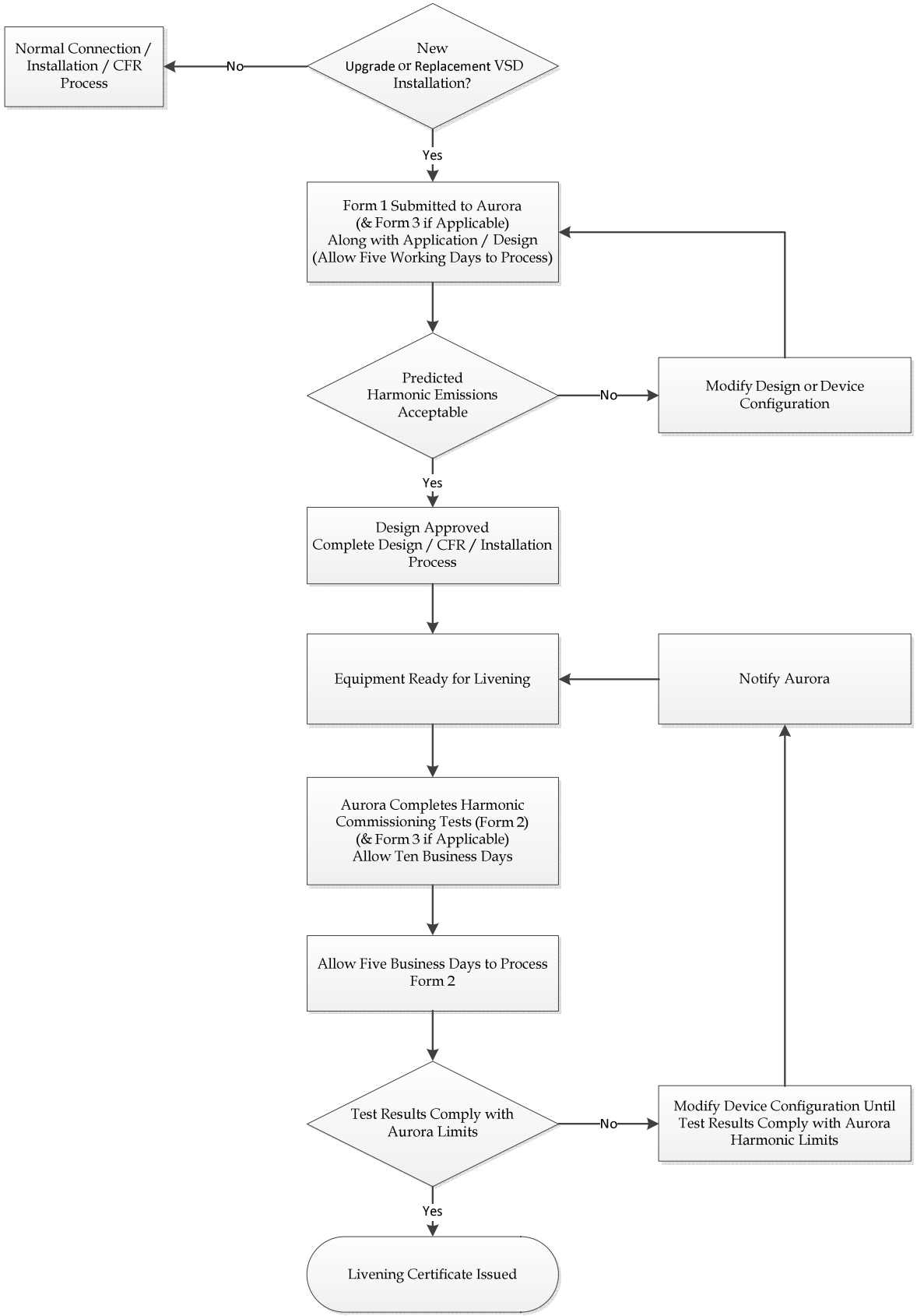



**Figure 1: VSD Connection Procedure**

## 8.3. APPENDIX C: Forms

Form 1: Manufacturers' Harmonic Data for New or Replacement Motor Control Equipment

Form 2: Commissioning Test Data for New or Replacement Motor Control Equipment

Form 3: Existing Motor Control Equipment

| FORM 1: MANUFACTURERS' HARMONICS DATA FOR NEW OR REPLACEMENT MOTOR CONTROL EQUIPMENT | | | |
|---|---|---|---|
| Harmonic emission certificate from the equipment manufacturer is to be submitted to Aurora in the following format. Attach a copy of nameplate data when available.<br>[Leave blanks if the information is not yet available]. | | | |
| Site Detail: | | | |
| Customer's Name: | | | |
| Contractor's Name: | | | |
| Number of VSD's: | | Existing VSD (Retrofit): | Yes ☐ No ☐ |
| VSD Manufacturer: | | Filter Manufacturer: | |
| VSD Model: | | Filter Model: | |
| VSD Rating: (kW/Amps) | | Filter Rating (kW/Amps) | |
| VSD Pulse Number | | Filter Type: | Active ☐ Passive☐ |
| Pump Type: | Surface ☐ Sub☐ | Motor rating (kW/Amps) | |

| HARMONIC SPECTRUM DATA | | |
|---|---|---|
| Background Voltage distortion (Assumed) | | |
| Voltage unbalance (Assumed) | | |
| Harmonic Number | Frequency (Hz) | Current Magnitude (Amps) |
| 1 | 50 | |
| 3 | 150 | |
| 5 | 250 | |
| 7 | 350 | |
| 9 | 450 | |
| 11 | 550 | |
| 13 | 650 | |
| 15 | 750 | |
| 17 | 850 | |
| 19 | 950 | |
| 21 | 1050 | |
| 23 | 1150 | |
| 25 | 1250 | |
| 27 | 1350 | |
| 29 | 1450 | |
| 31 | 1550 | |
| Notes/Comments: | | |
| Date: | | |
| Contractor Signature: | | |
| Company: | | |

Note 1: Harmonic spectrum data should reflect the harmonics spectrum of the installation.

| FORM 2: COMMISSIONING TEST DATA FOR NEW OR REPLACEMNT MOTOR CONTROL EQUIPMENT | | | |
|---|---|---|---|
| Commissioning test data will be collected by the Aurora's inspectors in the following format. Attach a copy of nameplate data when available. [Leave blanks if the information is not yet available]: | | | |
| Site Detail; | | | |
| Site Number: | | | |
| ICP Number: | | | |
| Installation Address: | | | |
| Substation / Feeder: | | | |
| Voltage Level: | | | |
| Transformer Serial Number /kVA: | | | |
| Customer's Name: | | | |
| Contractor's Name: | | | |
| Number of VSD's: | | Existing VSD (Retrofit): | Yes ☐ No ☐ |
| VSD Manufacturer: | | Filter Manufacturer: | |
| VSD Model: | | Filter Model: | |
| VSD Rating: (kW/Amps) | | Filter Rating (kW/Amps) | |
| VSD Pulse Number | | Filter Type: | Active ☐ Passive☐ |
| Pump Type: | Surface ☐ Sub☐ | Motor rating (kW/Amps) | |

| PRE-COMMISSIONING TESTS | | |
|---|---|---|
| Background Voltage distortion | | |
| $I_{sc}$ | | |
| $I_L$ | | |
| $I_{sc}/I_L$ | | |
| Voltage unbalance (VUF) | | |
| $THD_V$ | | |
| R | Y | B |
| | | |

| POST-COMMISSIONING TESTS | | | | | | | |
|---|---|---|---|---|---|---|---|
| Harmonic Load | $THD_i$ | | | $THD_v$ | | | $PF/PF_{dp}$ |
| | R | Y | B | R | Y | B | |
| 100% | | | | | | | |
| 75% | | | | | | | |
| 50%[1] | | | | | | | |
| 25%[1] | | | | | | | |
| 0% | | | | | | | |
| Notes/Comments: | | | | | | | |
| Date: | | | | | | | |
| Inspector Signature: | | | | | | | |

[1] If within equipment range

| FORM 3: EXISTING MOTOR CONTROL EQUIPMENT | | | | | | | |
|---|---|---|---|---|---|---|---|
| Equipment data for other notifiable drive equipment connected to the same transformer to be submitted to Aurora in the following format. Measurement will be required if details not provided. Attach a copy of nameplate data when available. [Leave blanks if the information is not yet available]: | | | | | | | |
| DRIVE DETAIL: | | | | | | | |
| Site Detail: | | | | | | | |
| Site Number: | | | | | | | |
| ICP Number: | | | | | | | |
| Installation Address: | | | | | | | |
| Substation / Feeder: | | | | | | | |
| Voltage Level: | | | | | | | |
| Transformer Serial Number /kVA: | | | | | | | |
| Number of VSDs: | | Existing VSD: | Yes ☐ No ☐ | | | | |
| VSD Manufacturer: | | Filter Manufacturer: | | | | | |
| VSD Model: | | Filter Model: | | | | | |
| VSD Rating: (kW/Amps) | | Filter Rating (kW/Amps) | | | | | |
| VSD Pulse Number | | Filter Type: | Active ☐ Passive☐ | | | | |
| Pump Type: | Surface ☐ Sub☐ | Motor rating (kW/Amps) | | | | | |
| PRE-COMMISSIONING TESTS (REQUIRED ONLY IF EXISTING DRIVE DETAILS NOT SUPPLIED) | | | | | | | |
| Background Voltage distortion | | | | | | | |
| $I_{sc}$ | | | | | | | |
| $I_L$ | | | | | | | |
| $I_{sc}/I_L$ | | | | | | | |
| Voltage unbalance (VUF) | | | | | | | |
| $THD_V$ | | | | | | | |
| R | Y | B | | | | | |
| | | | | | | | |
| POST-COMMISSIONING TESTS (REQUIRED ONLY IF EXISTING DRIVE DETAILS NOT SUPPLIED) | | | | | | | |
| | $THD_i$ | | | $THD_v$ | | | $PF/PF_{dp}$ |
| | R | Y | B | R | Y | B | |
| Harmonic Load | | | | | | | |
| Notes/Comments: | | | | | | | |
| Date: | | | | | | | |
| Inspector Signature: | | | | | | | |