Alberta Electric System Operator
3000, 240 4 Avenue SW
Calgary, AB • T2P 4H4
aeso.ca

AESO Connection Requirements for Transmission-Connected Data Centres

Draft for Stakeholder Review

August 22, 2025

Contents

1. Introduction

The Alberta Electric System Operator (AESO) has developed this document to set out specific technical requirements for connecting data centres to the Alberta transmission system.

Connection study scopes, functional specification documents and related operational details will reference the technical requirements within this document.

Some requirements address aspects of the transmission-connected data centre facility design or operational performance that are also addressed by ISO rules and Alberta Reliability Standards (ARS). The requirements specified in this document, ISO rules and ARS apply in such cases.

In cases of ambiguities or questions regarding the study requirements, please contact the AESO engineer assigned to the project.

2. Applicability

The AESO will apply these technical requirements to all existing and future data centres connected to the Alberta transmission system.

3. Definitions

Certain terms are defined specifically for use in this connection requirements document, and other terms are specific to the AESO Consolidated Authoritative Document Glossary (CADG) as follows:

Terms Specific to Connection Requirements	CADG Terms
• Data centre • Data centre tiers (Tier I – Tier IV) • Demand Transmission Service rate • Demand Opportunity Service rate • Emergency rating ratio • Facility owner • Load profile • Most severe demand contingency (MSDC) • Power factor • Power infrastructure • Power usage effectiveness (PUE) • Ramp30	• Active power • Apparent power • Designated transmission facility owner (TFO) • Emergency rating • ISO rules • Legal owner • Market participant • Normal rating • Point of common coupling • Point of connection • Remedial action scheme

Terms Specific to Connection Requirements	CADG Terms
• Rate DOS or DOS • Rate DTS or DTS • Temperature sensitivity curve • Transmission-connected data centre (TCDC)	• System access service • Transmission operator • Transmission system • Underfrequency load shedding (UFLS) • Unplanned outage

- A **data centre** is a facility that houses computing infrastructure, including processors, networking equipment, data storage systems, and associated control and monitoring technologies to process, store, and transmit digital information. These facilities support a wide range of digital applications and services, such as:
  - Data hosting and cloud computing
  - Artificial intelligence (AI) and machine learning (ML) training and inference
  - Digital services and content delivery
  - Blockchain operations and cryptocurrency mining
- A **transmission-connected data centre** (TCDC) is a data centre connected to the Alberta transmission system. This term encompasses all elements of the data centre facility, including the switchyard, facilitating connection to the transmission system and any on-site generation.
- In this document, TCDCs are categorized based on the Uptime Institute's Tier Standard[1], as follows:
  - **Tier I:** Basic infrastructure with no redundancy, susceptible to planned and unplanned outages
  - **Tier II:** Infrastructure includes partial N+1 redundancy, offering improved reliability but still allowing some downtime
  - **Tier III:** Provides full N+1 redundancy for all critical systems, including power supply and cooling distribution paths. Allows for maintenance without service disruption
  - **Tier IV:** Meets Tier III requirements but incorporates 2N+1 redundancy, ensuring fault tolerance and continuous operation even in case of multiple failures
- **Facility owner** may be various entities throughout the lifecycle of a TCDC. It includes the **market participant**, as defined for use in the ISO Tariff, developing a TCDC project and the **legal owner** of a TCDC at any point in time after Stage 6 of the AESO's connection process.
- **Demand Transmission Service rate** (Rate DTS or DTS): Rate DTS, as defined for use in the ISO Tariff, is the primary rate used for **system access service** on the transmission system for load customers.

[1] Uptime Institute, Tier Classification System, [Online]. Available: https://uptimeinstitute.com/tiers. [Accessed: Aug. 22, 2025].

- **Demand Opportunity Service rate** (Rate DOS or DOS): DOS, as defined for use in the ISO Tariff, allows eligible load customers to utilize additional capacity above their contracted DTS amount, on an as-available, interruptible basis.
- Emergency Rating Ratio is the percentage ratio of the emergency rating and the normal rating.
- **Load profile** represents the variation in **active power** and **apparent power** demand of the TCDC over time at the PCC. Hourly load profiles must include peak, average, and minimum demand over daily, weekly, and seasonal cycles for both active power and apparent power.
- **Most severe demand contingency** (MSDC) is the largest single demand loss the Alberta Interconnected Electric System (AIES) can accommodate**.**
- **Point of common coupling** (PCC), as used in this document, has the same meaning as defined in the AESO's CADG for use in ARS. For most circumstances in this document, it is assumed the TCDC has a single PCC[2].
- **Point of connection** (POC), as used in this document, has the same meaning as defined in the AESO's CADG for use in ARS. For most circumstances in this document, it is assumed the TCDC has a single POC.
- **Power infrastructure** refers to both the characteristics of the TCDC load and the physical assets that connect the TCDC to the AIES, as well as the distribution system within the TCDC facility. This includes substations, transmission lines, transformers, protection systems, and control equipment that ensure reliable and secure power delivery, and support monitoring and analysis of events associated with the facility.
- **Power factor** (PF) is the ratio of active power to apparent power at the PCC.
- **Power usage effectiveness** (PUE) is the ratio of the total facility energy usage to the IT equipment energy usage.
- **Ramp30** represents the total megawatt (MW) ramping over a 30-minute period, based on the maximum ramping limit allowable by the AESO for the TCDC. This is the ramp that can typically be managed in normal operations and is 300 MW per 30 minutes.
- **Transmission operator**, as used in this document, has the same meaning as defined in the AESO's CADG for use in ARS.
- **Temperature sensitivity curve** is the relationship between both TCDC's active power demand and the ambient (outdoor) air temperature by analyzing both the facility's net load measured at the PCC and gross load. With temperature precision to at least 0.1°C from the nearest weather station. The curve is constructed by grouping temperature data into 1°C bins and calculating the average load for each bin.

4. Applicable ARS and ISO Rules

TCDC are required to meet ISO rules and ARS requirements applicable for all load assets. TCDC with on-site generation connected to the transmission system**,** such generation is

[2] The appropriate adjustments will be made for facilities with more complex interfaces in their functional specifications.

required to meet ISO rules and ARS requirements applicable for generation assets. Also, due to the variety of TCDC designs and the TCDC's potentially significant impact on system reliability, TCDC may be required to comply with certain ISO rules and ARS that are applicable to generators, aggregated generating facilities, transmission facilities and energy storage facilities. The AESO may also specify additional requirements within the Functional Specification with which the TCDC must comply.

5. Characteristics and Design

5.1 General Infrastructure and Load Information

- To ensure accurate study assumptions, the facility owner is required to provide the most current TCDC Power Infrastructure Information throughout stages 0-6 of the AESO's connection process. The Data Centre Technical and Operating Characteristics must be completed as part of this requirement
- Table 1 summarizes critical information and indicates the stage of the connection process at which each item should be submitted
  - The facility owner is responsible for notifying the AESO of any changes to the information provided within 30 days at any stage of connection or after energization.
- After energization, the AESO reserves the right to request updated information on the actual load profile, temperature sensitivity curve, PUE, single line diagram, and operational characteristics to ensure alignment with system planning and operational needs
  - The facility owner must provide this data upon request and must submit the necessary data within 30 days of receiving the request

Table 1: Summary of Important TCDC Power Infrastructure Information and Required Study Stages

Information Item	Description	Required Stage
Ultimate Development Plan	Provide the facility's ultimate development plan, including the: • Timing of facility expansion • Load additions • BTF generation expansion at all stages of the project For each load stage, provide details of the seasonal load variability with respect to ambient temperature	0
Transmission Reliability Requirement	Confirm whether a specific transmission reliability requirement exists (e.g., multi-circuit connection)	1

Information Item	Description	Required Stage
Electrical Single-Line Diagram	Submit a single-line diagram as per AESO's SLD Guideline for Projects, including medium-voltage (MV) and all low-voltage (LV) feeders Refer to Appendix A for more information	1
Behind-the-Fence Generation	For any onsite generation, provide the: • Number • Type • Capacity	1
TCDC Tier Classification	Specify the TCDC Tier level in accordance with the Uptime Institute standard	3
Backup Generation	Specify the type of backup generation and the duration it can support partial and full TCDC load	1
Uninterruptible Power Supply (UPS)	Specify the: • Type of UPS system deployed (e.g., online, offline, or line-interactive) • Duration for which the UPS can support the connected load • Portion of the TCDC load that is supported by the UPS • Reconnection procedure for transferring the load back to the grid once normal grid voltage/frequency conditions are restored	2
MV Distribution System SLD	Submit the medium voltage[3] distribution system single-line diagram for the AESO review and acceptance	2
Voltage Levels and Redundancy Configuration	Provide voltage levels throughout the TCDC and the redundancy configuration (e.g., N, N+1, 2N)	2

[3] Medium voltage is the voltage supplied to the TCDC from the secondary side of the transformer(s) whose primary is connected to the transmission system. The voltage can generally range from 1 kV to 35kV.

Information Item	Description	Required Stage
Cooling/Heating Load Details	Provide electrical connection details and capacities (kW or tons) for: • Computer room air conditioners (CRACs) • Computer room air handlers (CRAHs) • Chillers • Pumps, etc.	2
Load Segmentation with Backup/UPS	Describe how internal loads are divided between UPS systems and backup generation	2
Load Ramp Rate (MW/min)	Specify the maximum load ramp-up and ramp-down rate (MW/min)	2
Islanding Operation Capability	Confirm whether the TCDC has the capability to operate in islanded mode (for co-located facilities)	3
Load Profile, Temperature Sensitivity Curve and PUE	Provide the typical load profile, PUE, and temperature sensitivity	3
Startup/Shutdown Sequence	Provide the sequence for startup and shutdown of the TCDC's electrical systems	3
Transfer Switch Logic and Procedure	Describe the logic and sequence for switching between utility and backup power supplies	3

5.2 Emergency Back-up Power

The on-site emergency backup generation must be configured and operated strictly as an emergency backup power source. The emergency backup generation must not be synchronized with the grid, unless it has been studied and approved for parallel operation through the AESO's connection process.

If the TCDC intends to operate on-site generation for purposes other than emergency backup (e.g., to respond to market price signals, for economic dispatch or to reduce energy costs during periods of high prices), such generation must follow the AESO's system access service request (SASR) process for generation.

5.3 Transmission Line and Substation

5.3.1 Design Fundamentals

No single event, including a stuck breaker or a breaker failure condition, can result in load loss greater than MSDC.

5.3.2 Transmission Line(s)

The number of circuits and capacity of transmission line(s) required for a TCDC is to be determined considering the limitations of MSDC, Ramp30, system operating limits (SOLs), and the SOL methodology[4] defined per FAC-011.

- For a single radial circuit, MSDC is a limiting factor for the SOL
- For multiple circuits:
  - Post-contingency, the maximum ramping limit allowable by the AESO must be adhered to when reaching new SOLs and preparing for the next contingency
  - Post-contingency, any exceeded SOLs (facility or MSDC) must be addressed within 30 minutes or less as defined by facility ratings (e.g. emergency ratings) in preparing for the next contingency
  - Line loading pre-contingency should result in no load loss from a single contingency
- Examples of the number of circuits and capacity of transmission lines can be found in Appendix B

The AESO will assess the cascade risk for events including double circuit tower failure and considering TCDC needed reliability will determine the need to split circuits onto separate structures or right-of-ways. Three or more circuits shall be split onto separate right-of-ways with consideration of feasible routing options, transmission line crossings and line length.

Minimum circuit capacity may consider future planned projects in the area.

5.3.3 High Voltage Substation

- No single bus fault or breaker failure event shall result in the loss of multiple transmission lines or multiple transformers that are supplying the same TCDC load
  - Simple bus and ring bus configuration are not permitted when the TCDC load is greater than MSDC
- Where multiple TCDC facilities in close proximity are expected or planned by different facility owners and the preferred solution to interconnect the TCDCs to the transmission system is a common facility, that facility must be a switching station owned and operated by the designated TFO
- Where multiple circuits supply the same TCDC load from a single transmission system interconnecting substation, the circuits must terminate on separate diameters

[4] AESO System Operating Limit Methodology for the Operations Horizon

- The number and capacity of transformers required to supply a TCDC load is to be determined considering the limitation of MSDC, Ramp30, SOLs and the SOL methodology[5] defined per FAC-011
  - For a single transformer-supported TCDC load, MSDC is a limiting factor for the SOL
  - For a set of parallel transformers supporting TCDC load, the following constraints must be maintained:
    - Post-contingency, the maximum ramping limit allowable by the AESO must be adhered to when reaching new SOLs and preparing for the next contingency
    - Post-contingency, any exceeded SOLs (facility or MSDC) must be addressed within 30 minutes or less as defined by facility ratings (e.g. emergency ratings) in preparing for the next contingency
    - Transformer loading pre-contingency should result in no load loss from a single contingency
  - Examples of the number and capacity of transformers required to supply a TCDC load can be found in Appendix B
  - Space separation or fire barriers will be a requirement between transformers to prevent the loss of more than one transformer as per the Alberta Electric Utility Code
  - Consideration should be provided for planned maintenance and credible outage scenarios when determining the TCDC design and the need for advanced protection schemes or curtailment

5.4 Medium Voltage Distribution

- Follow the AESO's SLD Guideline for Projects and see Appendix A for TCDC SLD examples
- Medium voltage is the voltage supplied to the TCDC from the secondary side of the transformer(s) whose primary is connected to the transmission system. The voltage can generally range from 1 kV to 35 kV
- No single event (including stuck breaker or breaker failure) on the medium voltage distribution system can result in load loss greater than the MSDC
- The SLD for the medium voltage distribution system must be reviewed by the AESO for acceptance
- Operational modes of the medium voltage distribution system for both normal and outage conditions must be provided to the AESO for review and acceptance

5.5 Protection and Control

- Protection and control requirements for 100 kV and above must follow Section 503.15 of the ISO rules
- Based on the complexity of the connection, the AESO may require hardware in the loop (HIL) testing of transmission line protections

[5] AESO System Operating Limit Methodology for the Operations Horizon

5.6 Isolating and Interrupting Devices

- The isolating and interrupting device requirements outlined in Section 503.10 of the ISO rules must be followed
- The legal owner of a transmission facility must have supervisory control to open the high-voltage breaker(s) at the TCDC

5.7 Grounding and Surge Protection

- Grounding and surge protection requirements outlined in Section 503.12 of the ISO rules must be followed
- If the TCDC plans to connect generation to the AIES, it must be designed to comply with effective grounding requirements for generators

5.8 Synchrophasor Measurement System

- All synchrophasor measurement system requirements from Section 503.13 of the ISO rules must be followed
- The TCDC must stream synchrophasor measurements to the AESO and comply with all synchrophasor measurement system requirements as specified in Section 503.13 of the ISO rules
  - This includes adherence to IEEE C37.118 standard and provision of as-build drawings in accordance with the rule

5.9 Digital Fault Recorder

- The TCDC must have digital fault recorders installed
- The requirements for digital fault recorders are detailed in subsection 10 of Section 503.15 of the ISO rules and PRC-002-AB-2

5.10 Telecommunication/SCADA Requirements

- TCDC facilities with load greater than or equal to 300 MW must have two SCADA telecommunication paths to the AESO, with one using the Utility Telecom Network (UTN) and the other using a commercial network
- TCDC facilities with load greater than or equal to 300 MW must have backup voice communications equivalent to those specified for generators in COM-001-AB-3
- Any substation built for connecting TCDC facilities to the transmission system with load greater than or equal to 500 MW, must have physically diverse telecommunication infrastructure

5.11 Operational Procedures

- The TCDC facility owner must create detailed operational procedures for the AESO to review that demonstrate the TCDC can safely reduce to MSDC on one line with controlled load ramp down capability (also refer to section 6.4 Ramping)

  - The detailed operational procedures must be verified by completing commissioning tests to confirm the ramp down capability of the TCDC
- Operational procedures must be contained within the TCDC
  - Procedures or design which involve the remedial action scheme of generators located elsewhere in the AIES are not acceptable

5.12 Power Quality

The TCDC must comply with all applicable power quality requirements, including voltage flicker, harmonics, resonance, rapid voltage change limits and voltage unbalance, as specified in Section 503.11 of the ISO rules. To establish a baseline characteristic and demonstrate initial compliance, the facility owner must arrange for voltage distortion measurements at the PCC to be conducted over a continuous one-week period during the following stages:

- Prior to energization of the TCDC
- After energization, and when the TCDC is capable of load consumption near its contracted full load level accounting for capacities under Rate DTS and Rate DOS.
- After power quality mitigations are implemented, if required

Compliance with power quality requirements is a continuous obligation throughout the operational life of the facility. Should a power quality issue arise at any point, the TCDC must investigate the issue and implement mitigation measures.

5.13 Reactive Power Capability

- The TCDC must be designed with sufficient reactive power resources to be capable of operating within ±0.95 PF of its full load contracted under Rate DTS and Rate DOS, as applicable, at the PCC
- The TCDC must be capable of the following mutually exclusive operating modes of reactive power control functions at the PCC:
  - Constant PF set-point mode between ±0.95
  - Voltage control mode within continuous operating range between 0.90 to 1.1 per-unit (p.u.). In this mode, the TCDC must operate in closed-loop automatic voltage control mode to regulate the steady-state voltage at the PCC to the reference set-point, within 1 percent of the PCC voltage set-point, with reactive droop adjustable from 0 percent to 10 percent.
  - Reactive power set-point mode
- The TCDC must be designed and operated to continuously meet voltage, PF and reactive power requirements, accounting for load variation
  - Reactive power compensation devices must be capable of continuously adjusting their output to satisfy the TCDC’s voltage, power factor and reactive power capability requirements under all operating conditions
- The facility operator must respond within 10 minutes to the AESO’s instructions to change the control mode and the set-point

- The reactive power tolerance for power factor and reactive power set-point control modes is ±1.75 percent of the TCDC's full load contracted under Rate DTS and Rate DOS, as applicable. The voltage tolerance for voltage set-point control mode is 1 per cent
- The voltage/reactive power control system must be operational except during forced outages of relevant equipment, planned maintenance outages, or as otherwise authorized by the AESO.
  - The facility owner ensure that the control system and reactive power resources are always in service and maintained to meet the requirements of this section
  - The facility owner must notify the ISO within 30 minutes after a status change, control mode change or change in reactive power capability
  - Reasonable efforts must be made to return equipment to service expeditiously when forced outages occur
- The step response must exhibit:
  - Reaction time less than 0.2 second
  - Rise time between 0.1 second and 1 second
  - Step response time less than 30 seconds
  - Damping ratio greater than 0.3

Notwithstanding the step response requirements, the facility owner should prioritize a stable, damped response in all operating conditions over response time, and seek variances to rise time and step response time requirements as needed to achieve stability in foreseeable operating conditions.

5.14 Ride-Through Capability

5.14.1 General Requirement

Unless stated otherwise, the applicable voltage and frequency in this section are at the PCC, and p.u voltages are based on the nominal voltage at the PCC.

The facility owner must design the entire TCDC, including its auxiliary systems, to meet the ride-through requirements specified in this section.

Voltage Measurement Requirements:

- Voltage must be measured with ± 2.5 percent measurement accuracy in the range of 0.1 to 2.0 p.u. of the nominal voltage
- Instantaneous trip settings based on instantaneously calculated voltage measurements with filtering lengths of less than one cycle (16.6 milliseconds) are not permissible

Frequency Measurement Requirements:

- Frequency must be calculated with ± 0.010 Hz minimum accuracy for fundamental frequency in the range of 48 Hz to 66 Hz when the positive-sequence voltage is greater than 10 per cent of the nominal positive-sequence voltage

- Frequency must be measured over a time window (typically 3-6 cycles) to calculate system frequency at the PCC; instantaneous or single points of measurement must not be used in the determination of protection settings

Protection Settings and Ride-Through Compliance:

- Notwithstanding the ride-through requirements, voltage and frequency protection trip settings, and other required protection elements related to voltage and frequency (e.g., phase angle jump, rate of change of frequency [ROCOF], V/Hz, etc.) must be set based on equipment capability
- The boundary of ride-through envelopes is not to be interpreted as a must-trip requirement
- Evidence such as setting reports, including original equipment manufacturer (OEM) capability curves, must be provided to the AESO to demonstrate that the TCDC protection settings are properly determined

Backup Generation Requirements:

- The use of any backup generation during a ride-through event is only permitted if its design and controls logic meet the AESO's ride-through requirements

5.14.2 Low- and High-Voltage Ride-Through

- The TCDC must be designed to ride through voltage disturbances of the magnitude and duration specified in Table 2
- The TCDC must ride through multiple voltage deviations at the PCC, which may occur in the transmission system due to various reasons, including trip and auto reclose events on a single transmission line and multiple faults on transmission lines during severe storms

Table 2: Low- and High-Voltage Ride-Through Requirements

Root-Mean Square (RMS) Voltage, V (pu)	Minimum Ride-Through Time (Seconds)[6]
V > 1.25	May ride through or may trip
1.20 < V ≤ 1.25	1
1.10 < V ≤ 1.20	1800
0.9 ≤ V ≤1.10	Continuous
0.75 ≤ V < 0.9	3
0.65 ≤ V < 0.75	2
0.45 ≤ V < 0.65	0.3
V < 0.45	0.15

[6] The specified minimum duration is cumulative over one or multiple disturbances within a 10 second window, unless the applicable voltage is greater than 1.1 p.u. and less than 1.20 p.u., in which case the duration is cumulative over one or multiple disturbances within a 3600 second window.

- The TCDC must not cease its current exchange with the transmission system and must not trip due to self-protection for disturbances that originate outside the facility, as described in Table 2
- The TCDC must use constant current control and must not use constant power level control during ride-through
- During a ride-through event, priority must be given to reactive current over active current to support grid voltages by:
  - Reducing reactive current consumption or increasing reactive current injection within the power factor capability range during low voltage ride through
  - Increasing reactive current consumption or decreasing current injection within the power factor capability range during high voltage ride through

5.14.3 Restore Output After Voltage Ride-Through

- After the voltage at the PCC returns to the continuous operation region per Table 3, the TCDC may restore active power consumption to 100 percent of the pre-disturbance level with the required power factor range at an average rate equal to its load contracted under Rate DTS and Rate DOS divided by the specified active power recovery time
- The active power recovery time must be configurable within a range between 1.0 second and 10 second
- The default active power recovery time is 1 second; however, in weak grids, to reduce the oscillatory behaviour of the TCDC upon fault recovery and maintain system stability, it may be required to reduce the average rate of active power recovery in consultation with the AESO

5.14.4 Transient Overvoltage Ride-Through

- The TCDC must be designed to ride through transient overvoltage of the magnitude and duration specified in Table 3
  - The voltages in Table 3 are the greater of individual phase-to-phase or phase-to-ground instantaneous voltages
- During the transient overvoltage ride-through, the TCDC must continue to maintain its pre-disturbance active and reactive power consumption. However, it does not have to respond to transient overvoltage, i.e., enter reactive current priority mode and/or change the magnitude of current output

Table 3: Transient Overvoltage Ride-Through Requirements

Instantaneous Phase-to-Phase or Phase-to-Ground Voltage, V (pu)	Minimum Ride-Through Time (Seconds)[7]
V > 1.8	May ride through or may trip
V >1.7	0.2
V >1.6	1.0
V >1.4	3.0
V >1.25	15.0

5.14.5 Low- and High-Frequency Ride-Through

- The TCDC must be designed to ride through frequency disturbances of the magnitude and duration specified in Table 4
- The TCDC must maintain pre-disturbance active and reactive power consumption during the frequency ride-through

Table 4: Low- and High-Frequency Ride-Through Requirements

Fundamental Frequency, F (Hz)	Minimum Ride-Through Time (Seconds)
F > 61.8	May ride through or may trip
61.2 < F ≤ 61.8	299
58.8 ≤ F ≤ 61.2	Continuous
57 ≤ F < 58.8	299
F < 57	May ride through or may trip

5.14.6 Rate of Change of Frequency Ride-Through

- Within the frequency ride-through range per Table 4, the TCDC must ride through frequency excursions having an absolute Rate of Change of Frequency (RoCoF) magnitude that is less than or equal to 5.0 Hz/s
- ROCOF must be calculated as the average rate of change of frequency over a rolling 0.5 second averaging window

[7] The specified minimum duration is cumulative over a 1-minute (60-second) time window. The cumulative duration shall only include the sum of durations for which the instantaneous voltage exceeds the respective threshold over the 1-minute (60-second) time window.

- The TCDC must maintain pre-disturbance active and reactive power consumption during the ROCOF ride-through event

5.14.7 Voltage Phase Angle Jump Ride-Through

- The TCDC must ride through positive-sequence phase angle changes within a sub-cycle-to-cycle time frame of the RMS voltage at the PCC of less than or equal to 25 electrical degrees
- The TCDC must ride through for any change in the phase angle of individual phases caused by unbalanced faults provided that the positive-sequence angle change does not exceed the 25-degree criterion
- The TCDC must maintain pre-disturbance active and reactive power consumption during the voltage phase angle jump ride-through

5.14.8 Volts per Hz (V/Hz) Ride-Through

- The TCDC must ride through grid disturbances with V/Hz, measured at the PCC, of at least 1.1 per unit for 45 seconds and 1.18 per unit for 2 seconds
- The TCDC must maintain pre-disturbance active and reactive power consumption during the V/Hz ride-through

5.15 Underfrequency Load Shedding

The TCDC must have the provision for the capability to:

- Selectively trip a portion of its load up to its entire load under an underfrequency load shedding (UFLS) program the ISO establishes
- Automatically adjust reactive compensation devices within the facility to meet reactive power capability requirements (refer to 5.13 power quality) and control over-voltage as a result of underfrequency load shedding if required by the UFLS program

5.16 Undervoltage Load Shedding

The TCDC must have the provision for the capability to:

- Selectively trip a portion of its load up to its entire load under an undervoltage load shedding (UVLS) program the ISO establishes

6. Operational Requirements

6.1 Operational Readiness

The facility owner must designate both a primary and a backup 24/7 operational point of contact. Each must be sufficiently trained, authorized and capable of the following:

- Continuous system monitoring and supervisory control
- Continuous communication capability with the AESO
- The ability to respond as soon as practicable to the AESO instructions

6.2 Demand Reconnection

The operator of the TCDC must, once the connecting breaker(s) of the TCDC has been disconnected (opened or tripped) from the transmission system, request and receive approval from the AESO before electrically reconnecting to the transmission system. Installation of automatic reconnection systems must be subject to prior authorization. Approved auto-reclose single pole trip and reclose schemes on transmission lines are excluded from this requirement.

The TCDC must be capable of reconnection for continuous operation frequencies.

6.3 Operational Plan

The TCDC must submit planned load outages to the AESO, according to ISO rule 306.3, which may be included in supply adequacy assessments and forecasts.

The TCDC must submit an operational plan that includes hourly average net load at the PCC for the next 7 days, which may be included in supply adequacy assessments and forecasts.

6.4 Ramping

The TCDC must limit load ramping to maximum ramp rate of 10 MW/min.

6.5 Load-Induced Forced Oscillation

- The TCDC must be designed to prevent the emergence of forced oscillations that may arise from internal load dynamics, such as repetitive control actions, cycling behaviour, fast ramping or abrupt power demands
- To limit the risk of power oscillations, the TCDC’s net load variability must be limited to less than 16 kW per 100 milliseconds
- Forced power oscillation amplitude within sub-synchronous frequency band must be limited to less than ± 160 KW
- These indicative values may be refined based on system-specific electromagnet transient (EMT) studies, accounting for local grid strength, connection configuration, and facility control behaviour
- The design must incorporate appropriate mitigation measures to minimize the potential risk of such oscillations
  - These measures should be selected based on the TCDC’s operational characteristics, interaction with the grid, and the findings of relevant technical studies
  - For example, current industry practices include using technologies such as battery energy storage system (BESS), E-STATCOMs, soft-start or ramp-rate controls to address forced oscillations

Figure 1 shows an example of acceptable oscillatory behaviours. The amplitude of the oscillatory components shown in Figure 2 are less than 160 kW.

Figure 1: Example of 60-Second Load with Oscillatory Components

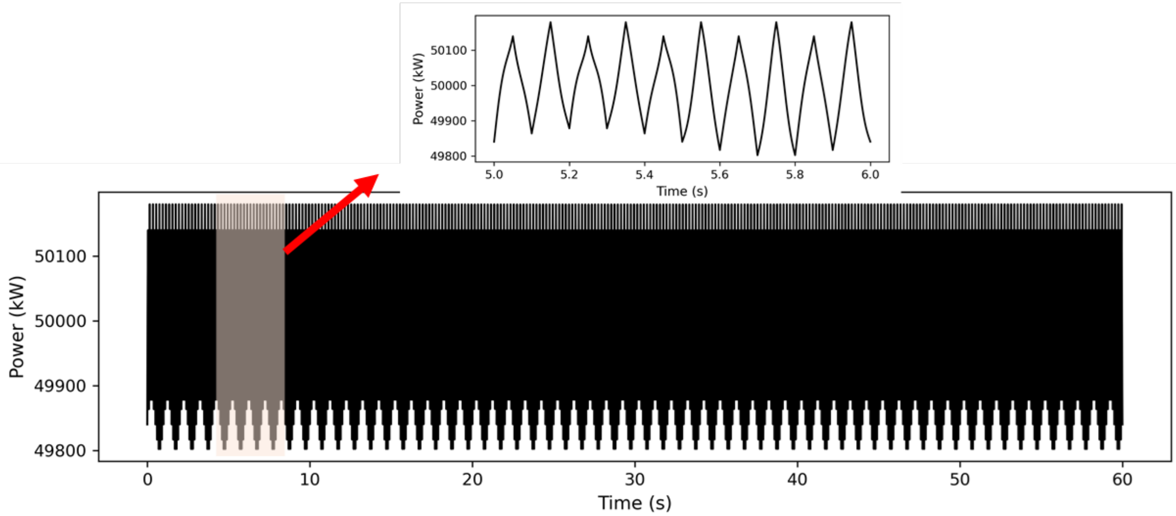
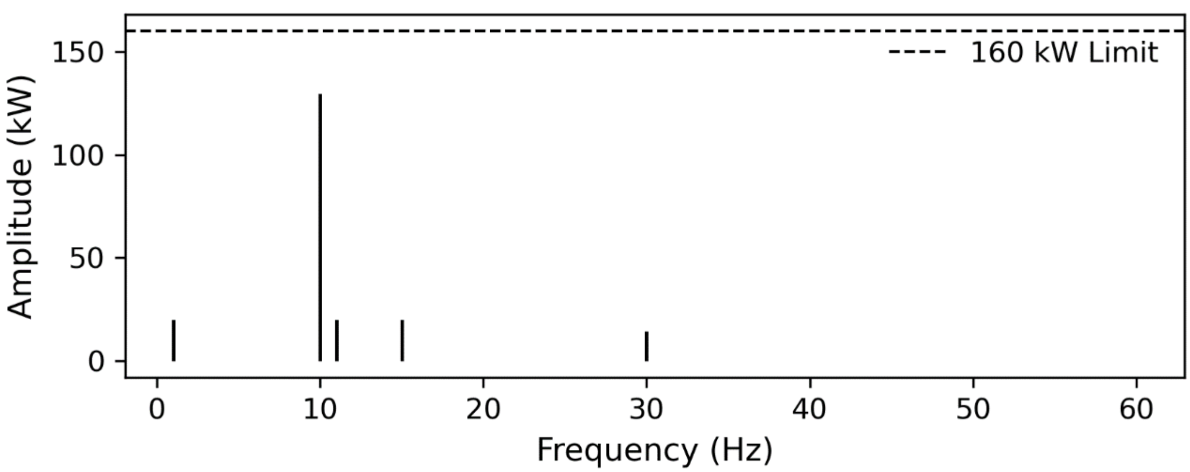


Figure 2: Amplitude and Frequencies of Figure 1 Oscillatory Components



6.6 Control Stability

The TCDC must be designed and operated to avoid contributing to or amplifying oscillatory modes across a broad frequency range, specifically targeting:

- Very low to low-frequency modes (0.1–3 Hz): Interarea and local electro-mechanical modes
- Sub-synchronous and torsional frequency modes (3–60 Hz): Including oscillations excited by weak grid conditions, series-compensated transmission lines, or torsional interactions in turbine-generator shafts
- Power electronic device (PED) driven oscillations: Resulting from interactions between internal control loops of inverter-based resource (IBRs), high-voltage direct current (HVDC), Flexible AC Transmission System (FACTS) devices and the grid

- Harmonic resonance modes: Resonances that may occur in the grid at frequencies extending up to several kHz

The following considerations must be respected at the design stage:

- Robust tuning of control systems to maintain stability across varying grid conditions
- Implementation of active damping strategies
- Avoidance of control configurations that can lead to limit-cycle (control cycling) behaviours or negative damping effects

7. Connection Study Requirement

7.1 Project Modelling

7.1.1 Phasor Domain Modelling Requirement

7.1.1.1 Model Components

For steady-state analysis, the load model can be represented as a constant power (P) load if all machines in the TCDC are connected through variable frequency drives (VFDs). This is because VFDs typically operate in a way that maintains a constant power consumption regardless of voltage variations. However, if non-VFD-driven machines greater than or equal to 5 MW are part of the load, then this portion of the load should be modelled as machines, as their power consumption is more closely related to voltage and impedance characteristics.

To evaluate the dynamic stability responses of the loads, the TCDC must submit a project-specific User Defined Model (UDM) that includes the ride-through settings and the dynamic reactive power capability of the facility, to the best of the facility owner's knowledge.

In addition, the TCDCs are represented by a Western Electricity Coordinating Council (WECC) approved composite load model (CMLD). This model comprises static ZIP loads, motor loads and electronic loads. It provides a more accurate representation of the TCDC for stability studies by having a combination of load components each with distinct electrical and dynamic characteristics, to provide a realistic load representation as per North American Electric Reliability Corporation (NERC) Load Composition Guideline[8].

Currently, CMLDBLU1 and CMLDBLDGU2 are the approved WECC Dynamic Models. However, CMLDBLU2, an updated version of CMLDBLU1, is available in PSS®E and is widely adopted across North America. When a more accurate and representative dynamic model for data centers is approved by NERC, its adoption will be required to ensure reliable system studies that reflect actual data center behaviour. The facility owner is expected to submit the updated model within 180 days from the time it becomes available, regardless of the project stage.

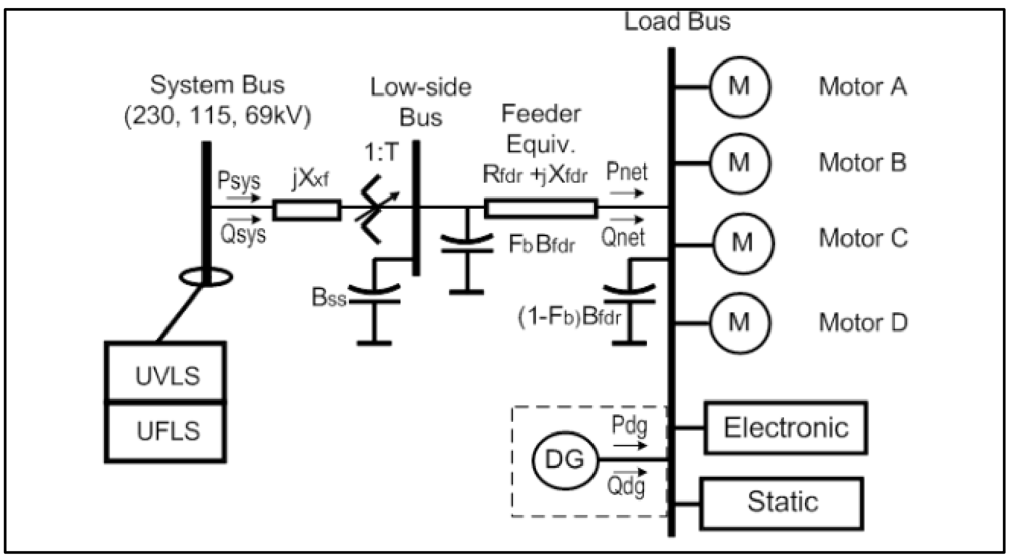
To accurately model TCDC loads in CMLD, the following components should be considered:

[8] North American Electric Reliability Corporation, Reliability Guideline: Load Model Composition, Feb. 28, 2017.

- Motor A: Low-inertia, constant-torque three-phase induction motors, commonly found in chiller compressors for centralized cooling
- Motor B: High-inertia, quadratic-torque three-phase induction motors, used in air handling units and large ventilation fans
- Motor C: Low-inertia, quadratic-torque three-phase induction motors, typically water circulation pumps in cooling systems
- Motor D: Single-phase motors, mainly for small A/C units, relevant in smaller-scale data centres
- Electronic Load: The dominant category, consisting of servers, routers, switches, UPS and power conditioning systems

If the TCDC is a part of a load-shedding program, a load-shedding model must be provided. Currently, LDS3BL is approved by WECC for this purpose.

Figure 3: CMLD Representation from NERC Load Composition Guideline



7.1.1.2 Model Applicability

The models will be used in various studies. Therefore, the accuracy and usability of these models must meet the minimum requirements necessary for effective application in the following studies:

- Steady state category A, B and C analysis
- Short circuit calculation
- Voltage stability
- Switching studies
- Transient stability

All phasor domain models must be capable of stable operation using a ¼ cycle timestep.

7.1.1.3 Dynamic Model Validation and Quality Testing

The facility owner must adhere to any requirements in Sections 503.19 and 503.20 of the ISO rules which are applicable to their TCDC, according to the type of equipment being installed.

In addition, the facility owner must perform baseline testing or otherwise provide evidence based on real-time measurements to validate model accuracy for the following:

- Requirements established in Section 5.12 of this document
- Requirements established in Section 6.5 of this document

Reporting requirements for the above tests shall follow subsection 4 of Section 503.19 and subsection 7 of Section 503.20 of the ISO rules. Modifications to the TCDC which impact the behaviour of the above requirements require model revalidation to be performed and submitted to the AESO as per subsection 7(2) of Section 503.20 of the ISO rules

Model quality testing must also be performed, and a Model Quality Testing Report provided to the AESO to verify model performance. At a minimum, this must include:

- Flat Start
- Voltage and frequency step tests
- Voltage and frequency ride-through
- Faults

Further details regarding the Model Quality Testing Report are outlined in Appendix 4 of Information Document #2010-001R.

7.1.2 Electromagnetic Transient Modelling Requirement

In general, the submitted EMT models for TCDC must meet the applicable accuracy, usability, and efficiency. Requirements outlined in Information Document 2010-001R[9] section A3.3.2. If the TCDC's design includes electric machines used for heating or cooling purposes depending on the Tier class, the model needs to meet the applicable modelling requirements set out in Section A3.3.3.

7.1.2.1 Model Components

Depending on actual TCDC configuration, the EMT model must include detailed representations of:

- Load Profile: a high-resolution, time-series load profile must be represented for each major load group, including IT load, cooling load, etc., at the distribution side of the TCDC
  - The time resolution must be sufficient to capture fast load variations, including inrush, step changes, or sub-second fluctuations
  - The profile must reflect worst-case loading scenarios, considering magnitude and variability across all operating modes

[9] https://www.aeso.ca/assets/Information-Documents/2010-001R-Facility-Modelling-Data-2024-04-19.pdf

- UPS Systems controls: detailed representation of control loops (inner and outer), ride-through behavior (both voltage and frequency), phase locked loop and fault response and limitations
- Static Switches and Bypass Circuitry: detailed modelling of switching mechanisms and bypass logics
- Power electronic converters: detailed representation of AC/DC and DC/DC conversion schemes including controls and protections
- Variable-Speed Drive Systems and electric motors including controls and protections[10]
- Protective Functions or Relays: to represent operational behavior
- Plant: detailed representation of plant control including any delays that affect performance, harmonic filters, main power transformers and grounding transformers including the saturation characteristics, transformer tap-changer controls

7.1.2.2 Model Applicability

The EMT model provided for large data centres will be used in various EMT studies. Therefore, the accuracy and usability of these models must meet the minimum requirements necessary for effective application in the following studies:

- Ride-through studies
- Small signal stability (e.g., forced oscillations at low frequencies)
- Power quality studies (e.g., harmonics, flicker, ramping)
- Sub-synchronous resonance analysis (e.g., torsional interactions with turbine-generator units, sub-synchronous ferro-resonance)
- Protection studies (e.g. coordination studies, short circuit and breaker duty studies)
- Effective grounding study
- Control interactions

Note: Where aggregation of model components is necessary due to simulation computational limitations, the aggregated representation must reasonably capture and reflect the dynamic response and behaviour of the TCDC, particularly for the intended study objectives.

7.1.2.3 Model Quality Testing

The facility owner must provide a Model Quality Testing Report. The AESO will review the report and submitted models, addressing any identified deficiencies with the facility owner as needed.

As a minimum, the following tests must be performed for model validation and model quality testing:

- Voltage and frequency ride-through

[10] As a minimum, models must include the main control and protection systems that have a material impact on performance and ride-through response.

- Voltage and frequency step tests
- System strength
- Faults
- Flat start
- Phase angle jump

Further details regarding the requirements are outlined in Appendix 4 of Information Document #2010-001R.

7.2 Required Studies

Table 5 summarizes the studies that are required at different stages of the connection process for TCDCs.

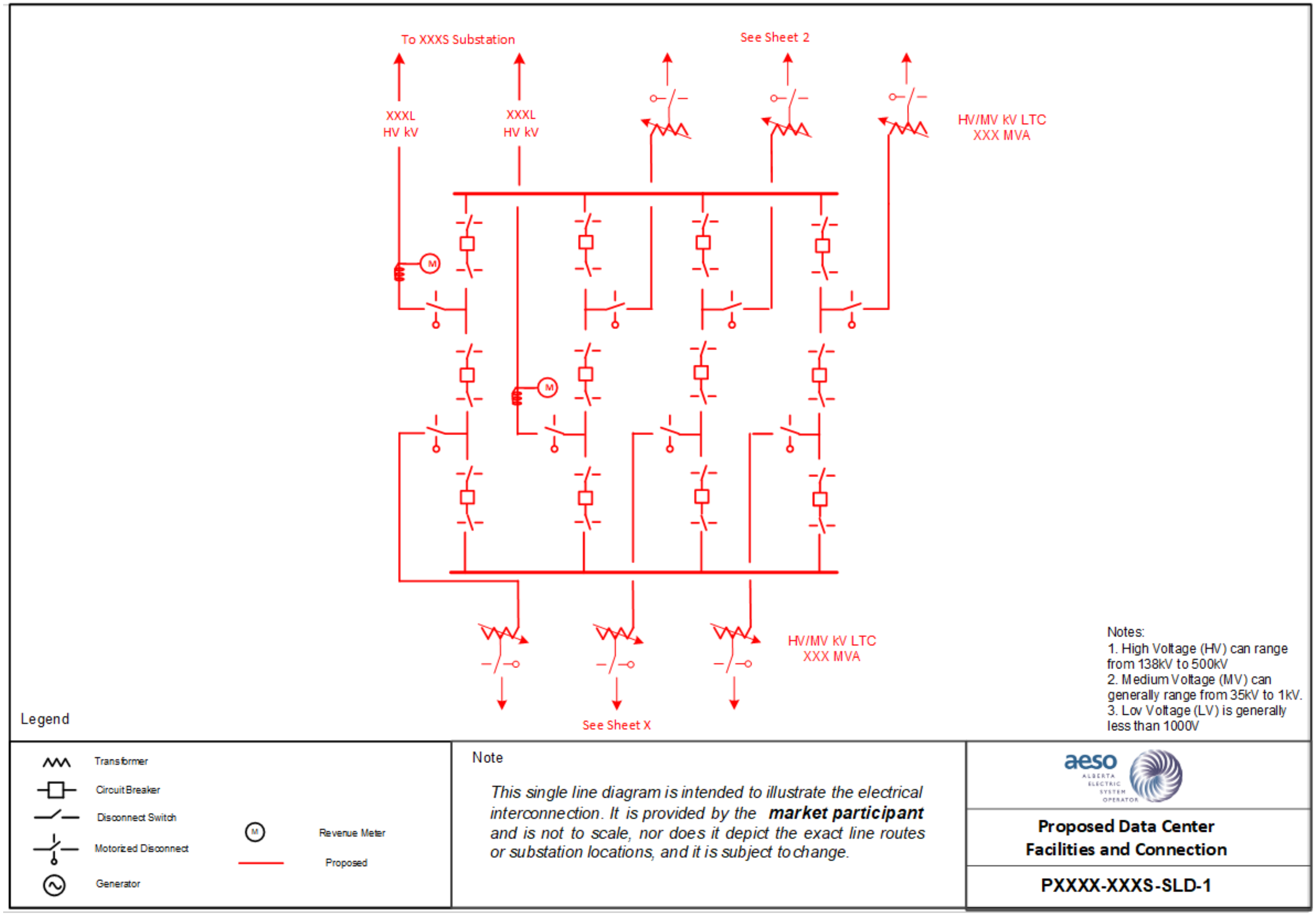
Table 5: Summary of Studies Required

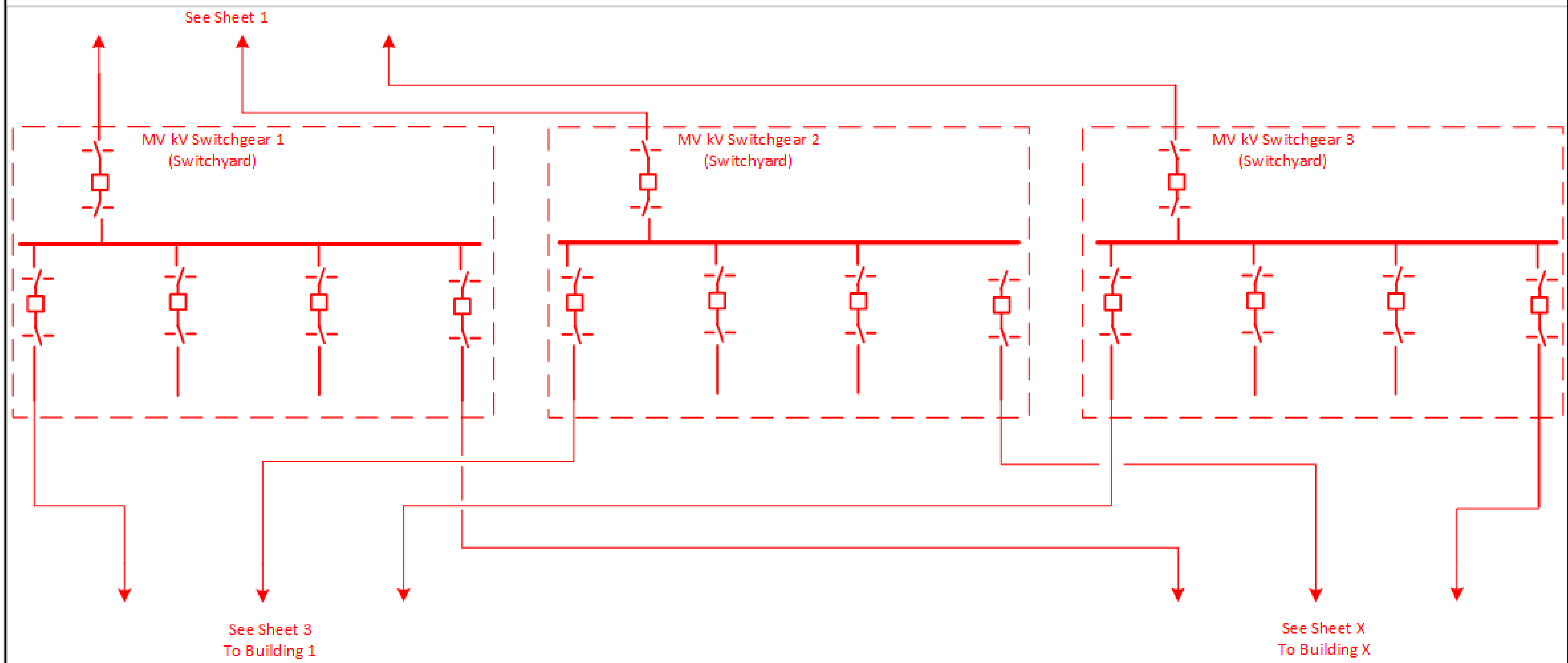
Study	Description	Stage Required
Power Flow Analysis	Under Category A, B and selected Category C (e.g., C3, N-1-1) conditions across scenarios such as summer peak (high/light generation) and winter peak (high/low generation), any steady-state voltage or thermal violations require mitigations These may include new remedial action schemes, use of TCDC backup generation, real-time operation practices or system upgrades	2 & 3
Voltage Stability	Post-transient voltage stability margin in low gen scenarios is required for the area modelled at a minimum of 105 percent of the reference load level for Category A conditions and for Category B conditions Any voltage stability risks require mitigation. These may include additional reactive power support, system upgrade, etc.	2 & 3
Transient Stability	The objective is to assess whether the addition of the TCDC load introduces new stability concerns or exacerbates existing ones Any violations of the transient voltage response requirements outlined in WECC TPL-001-WECC-CRT-3.1 must be	3 & 5

Study	Description	Stage Required
	identified. The activation of protection schemes, including ULFS and UVLS, must be reported Any load tripping resulting from voltage or frequency protection must be assessed to ensure compliance with ride-through requirements and MSDC If dynamic instability is observed, appropriate mitigation measures—such as network or system upgrades, operating guides, or remedial action schemes—must be developed and implemented	
Short-Circuit	To be performed to determine the magnitude of fault currents experienced at the substation breakers during different fault events, including three-phase and single-line-to-ground.	2 & 3
System Strength Assessment	As per the AESO's upcoming system strength assessment guideline, in Stage 2 a screening assessment is required. This study assesses the recovery time after a voltage ride-through event If the screening assessment identifies a risk of system strength shortfall, a detailed EMT-bases assessment is required as specified in the guideline To mitigate the instability in the weak systems, a combination of approaches targeting both grid infrastructure and the control systems of power electronic converters in TCDC is essential	2 & 3
Harmonics Assessment	As per the AESO's upcoming harmonic analysis study guideline, an EMT-based assessment is required to ensure compliance with Section 503.11 of the ISO rules Harmonic mitigation can be approached through various methods, including the installation of passive or active filters, equipment upgrades, network reconfigurations, etc.	3
Switching Study	Switching studies might be required for Category A conditions to evaluate rapid voltage changes caused by TCDC or reactive power compensator switching events The need will be identified based on the specifics of the TCDC interconnection. These studies ensure compliance with Section 503.11 of the ISO rules	3

Study	Description	Stage Required
Transformer Energization Assessment	As per the AESO's upcoming transformer energization assessment guideline, this study must ensure that transformer energization does not adversely affect the surrounding system, including the transmission network and data centre medium-voltage distribution A screening analysis must be conducted in Stage 2, followed by a detailed EMT-based assessment in Stage 3 if required Hardware mitigation (e.g., Point-on-Wave controller) must be installed on the main transformer high voltage (HV) breaker if recommended by the studies	2 & 3
Sub-synchronous Oscillation (SSO) Assessment	As per the AESO's upcoming sub-synchronous oscillation assessment guideline, a screening analysis shall be performed in Stage 2 to evaluate the potential for SSO If a moderate to high risk is identified, a detailed EMT-based study must be conducted in Stage 3 to assess interactions with HVDC links, FACTS devices, Type 3 and 4 wind turbines, solar inverters, energy storage systems, series capacitors, and synchronous generators Mitigation measures must be implemented if unacceptable SSO risks are found	2 & 3
System Restoration Cranking Path Assessment	As per the AESO's upcoming system restoration cranking path assessment guideline, connection alternatives located on the cranking path associated with a contracted blackstart unit must be identified These must be communicated with the System Resiliency team, and restoration studies may be required in Stage 2 at their discretion	1 & 2

Appendix A: Single Line Diagrams





Notes:
1. High Voltage (HV) can range from 138kV to 500kV
2. Medium Voltage (MV) can generally range from 35kV to 1kV.
3. Low Voltage (LV) is generally less than 1000V

Legend

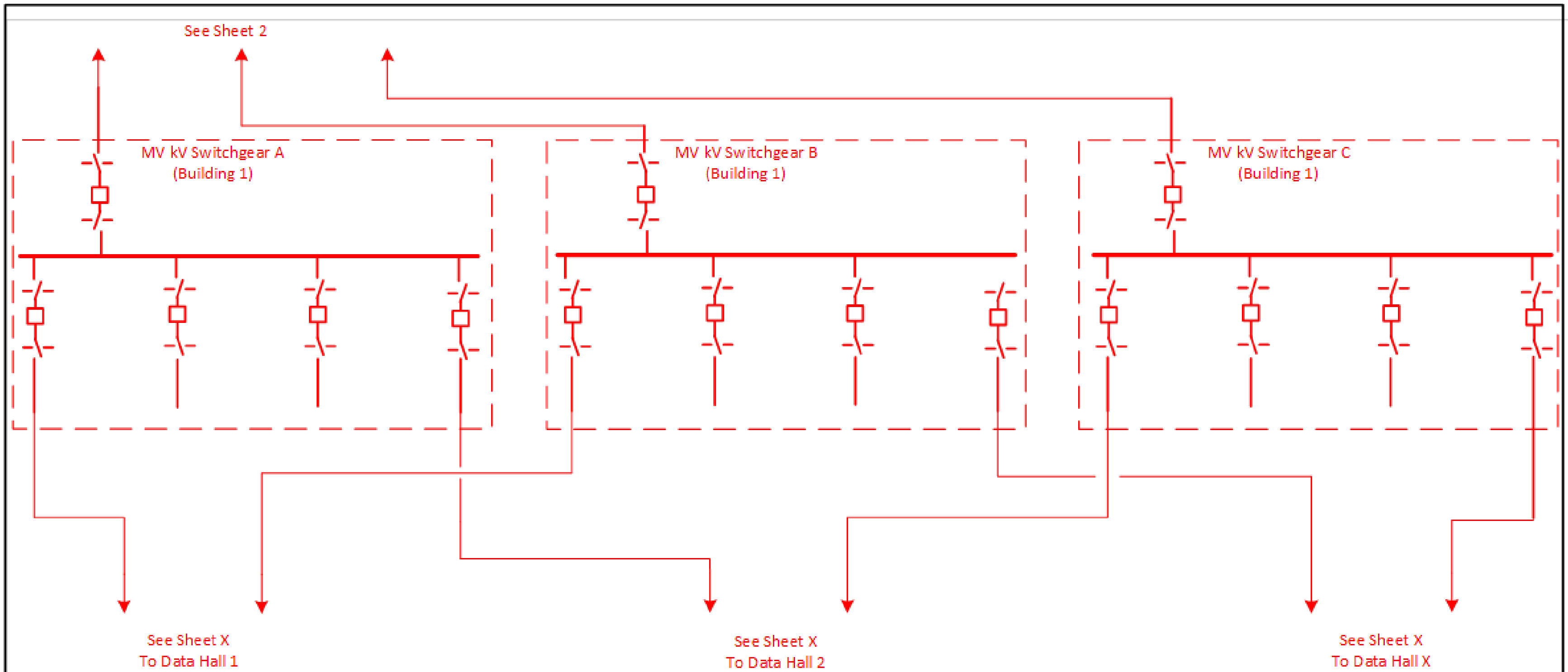
Transformer	Revenue Meter
Circuit Breaker	Proposed
Disconnect Switch	
Motorized Disconnect	
Generator	

Note

This single line diagram is intended to illustrate the electrical interconnection. It is provided by the ***market participant*** *and is not to scale, nor does it depict the exact line routes or substation locations, and it is subject to change.*

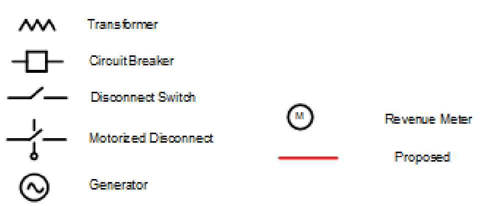
Proposed Data Center Facilities and Connection

PXXXX-XXXS-SLD-2



Notes:
1. High Voltage (HV) can range from 138kV to 500kV
2. Medium Voltage (MV) can generally range from 35kV to 1kV.
3. Low Voltage (LV) is generally less than 1000V

Legend



Note

This single line diagram is intended to illustrate the electrical interconnection. It is provided by the ***market participant*** *and is not to scale, nor does it depict the exact line routes or substation locations, and it is subject to change.*

Proposed Data Center Facilities and Connection

PXXXX-XXXS-SLD-3

Appendix B: Transmission Line and Transformer Examples

Example of Transmission Line Circuits and Capacity for TCDC

TCDC Size (MW)	Min # of Circuits	Minimum Circuit Capacity (MVA)	Limitations	Next Contingency Loading (MW)
200	1	210.5	MSDC	0
500	2	526.3	MSDC + Ramp30	200
800	3	526.3	MSDC + 2 x Ramp30	500
1000	3	1052.6	N-2 Design (large circuit capacity)	500
1000	4	526.3	N-2 Design (small circuit capacity)	800
2000	4	1052.6	N-2 Design (large circuit capacity)	1000
Assuming: *MSDC* = 200 MW; Ramp30 = 300 MW in 30 minutes; PF = 0.95				

Example of Transformer Quantity and Capacity for TCDC Load

Parallel Transformers	Parallel Transformer Capacity Limit (MW) [Limitation]		
Transformer Rating ->	Transformer Size 225 MVA (214 MW)	Transformer Size 400 MVA (380 MW)	Transformer Size 500 MVA (475 MW)
1	200 MW [MSDC]	200 MW [MSDC]	200 MW [MSDC]
2	235 MW [214 MW x Emergency Ratio]	418 MW [380 MW x Emergency Ratio]	500 MW [MSDC + Ramp30]
3	470 MW [2 x 214 MW x Emergency Ratio]	800 MW [MSDC + 2 x Ramp30]	800 MW [MSDC + 2 x Ramp30]
4	706 MW [3 x 214 MW x Emergency Ratio]	1100 MW [MSDC + 3 x Ramp 30]	1100 MW [MSDC + 3 x Ramp30]
Assuming: MSDC = 200 MW; Ramp30 = 300 MW in 30 minutes; PF = 0.95; Emergency rating ratio 110%			