Guide to AESO Connection Requirements for Transmission-Connected Data Centres

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

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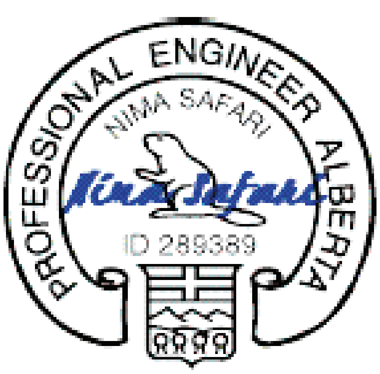
Role	Name(s)
Prepared	Nima Safari, Mahdi Hajian, Siavash Zoroofi, David Waenink, Ralph Liu, Peyman Ahmadi, Ashneel Prahlad, Stephen VanderZande, William Chow, Sam Amiri
Reviewed	Cam Bush, Pravin Koshti, Robert Davidson, Gillian Barnett, Marco Ciofani, Eric Viray, Mahmoud Ahmed, Ping-Kwan Keung, Changling Luo, Tom Sloan, Chris Connoly, Bre Fox
Approved	Cam Bush, P.Eng Pravin Koshti, P.Eng



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INDEPENDENT SYSTEM OPERATOR
RM SIGNATURE: Koshti
RM APEGA ID #: 110749
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Executive Summary

This guidance document explains the technical requirements established by the Alberta Electric System Operator (AESO) for connecting transmission connected data centres (TCDCs) to Alberta's transmission system. It's designed to help developers understand the obligations they will be required to meet to ensure their facilities operate reliably within the Alberta Interconnected Electric System (AIES). As demand for data centre connections grows, these requirements provide a framework to safeguard system reliability and efficient grid integration.

The AESO's TCDC requirements are implemented through the following:

- **ISO Rules and Alberta Reliability Standards**: These apply to all transmission-connected data centres, regardless of size, and set technical standards to maintain grid reliability.
- **Project-specific Functional Specifications**: These are tailored to individual TCDC projects and issued by the AESO to address specific technical needs.

This guide should be read in conjunction with ISO rules, Alberta Reliability Standards and AESO Functional Specifications. In the event of a conflict, these authoritative documents take precedence.

Why TCDC Requirements Are Necessary

The AESO's responsibilities include providing fair and non-discriminatory access to Alberta's transmission system and reliably operating the grid. TCDC requirements help the AESO to fulfil these responsibilities by:

- Recognizing the unique attributes of data centres
- Providing technical specifications for connecting data centres to the transmission system
- Setting a framework for operations that supports reliable system performance

Alberta's grid characteristics

Alberta's grid is comparatively smaller and less interconnected compared to most North American jurisdictions:

- Alberta average internal demand is approximately 10.2 gigawatts.
- Alberta has only two AC interties (British Columbia and Montana), both with limited transfer capability to the Western Interconnection.
- System inertia (the grid's resistance to sudden changes) and primary frequency response (PFR) is limited and can be very low – particularly during periods of low demand and high renewable generation – making the system more sensitive to large load disturbances.

These characteristics create operational risks, including:

- The potential for intertie trips caused by power surges following major load disturbances.
- The potential for cascading outages caused by the sudden loss of a large data centre, driven by significant supply-demand imbalance while islanded.

- Increased sensitivity to system disturbances such as:
  - Voltage fluctuations
  - High load variability oscillations
  - Rapid ramping requirements
  - Supply and demand imbalances

What Developers Need to Know

The AESO's TCDC requirements have been developed based on current and anticipated grid capabilities through 2030. Developers must comply with two primary frameworks:

1. Applicable ISO rules and Alberta Reliability Standards
2. Project-specific Functional Specifications issued by the AESO for each data centre:
   - Provides clear connection requirements for a data centre
   - Defines the required facility capabilities of a data centre to ensure system reliability

It's the responsibility of a data centre market participant to comply with a Functional Specification the AESO issues for its facility.

Alignment with North American Standards

The AESO's TCDC requirements aim to ensure the safe, reliable and economic operation of the power system, while supporting Alberta's data centre sector and align with the AESO's Reliability Requirements Roadmap (R3), focusing on:

- System strength and stability
- Flexibility and balancing
- Frequency response

These requirements also align with work underway by the North American Electric Reliability Corporation (NERC)'s Large Loads Working Group (LLWG)[1] and other industry initiatives, which focus on:

- Studying data centre characteristics across North America
- Evaluating reliability challenges posed by data centres
- Developing mitigation measures to ensure bulk power system reliability

The AESO will incorporate insights from the LLWG and other entities into its future versions of TCDC connection requirements, as appropriate for the AIES.

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[1] In December 10, 2025, The NERC Large Loads Task Force was promoted to Large Loads Working Group.

1. Applicability

The AESO will review all transmission-connected data centre facilities, regardless of size, to determine whether the TCDC requirements and mitigations referred to in this guide are appropriate.

The connection of data centres on distribution systems could also impact the transmission system. In such cases, the AESO expects that the relevant DFO and facility owner will work with the AESO to ensure the project will connect and operate reliably in a manner that does not impact the transmission system. Data centres connecting to the distribution system can review this guide of TCDC requirements and mitigations for specific reliability concerns the AESO and DFOs may seek to address.

2. 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
• Back-up generator • Behind-The-Fence (BTF) generator • Data centre • Data centre tiers (Tier I – Tier IV) • Rate Demand Transmission Service (Rate DTS or DTS) • Rate Demand Opportunity Service (Rate DOS or DOS) • Emergency ratio rating • Facility owner • Load profile • Most severe demand contingency (MSDC) • Power factor • Power infrastructure • Power usage effectiveness (PUE) • Ramp30 • Temperature sensitivity curve • Transmission-connected data centre (TCDC)	• Active power • Apparent power • Designated transmission facility owner (TFO) • Emergency rating • ISO rules • Legal owner • Market participant • Normal rating • Point of common coupling (PCC) • Point of connection (POC) • Project Change Proposal • Remedial action scheme • Supply Transmission Service (STS) • System access service • System operating limit (SOL) • Transmission operator • Transmission system • Underfrequency load shedding (UFLS) • Unplanned outage

- A **data centre** means a facility or facilities, or a proposed facility or facilities, the purpose of which is to house and operate computing equipment for applications including data hosting and cloud computing, digital asset mining, artificial intelligence and machine learning and digital services and content delivery.
- 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[2]:
  - **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** refers to the market participant requesting or receiving system access service from the AESO for the TCDC. The facility owner may change at various stages of a TCDC's lifecycle, and may include:
  - The entity developing the TCDC in the early stages of the AESO connection process
  - The entity constructing the TCDC in the later stages of the AESO connection process
  - The entity owning/operating the TCDC after energization
  - The DFO for a TCDC that was not granted a Section 101 waiver to obtain service directly
- **Rate Demand Transmission Service** (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.
- **Rate Demand Opportunity Service** (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.
- **Backup generation** provides emergency power to data centre when the data centre is disconnected with the transmission network and will not synchronize with the AIES in any operating scenarios.
- **Behind-The-Fence (BTF) generation** is located behind the point of connection of data centre. It can synchronize with the AIES, and it must be registered as a pool asset in Alberta market.
- **Emergency Ratio Rating** is the percentage ratio of the emergency rating and the normal rating for substation equipment.

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

- **Load profile** represents the variation in **active power** and **apparent power** demand of the TCDC over time at the PCC. Hourly load profiles include peak, average, and minimum demand over daily, weekly, and seasonal cycles for both active power and apparent power.
- **Most severe demand contingency**[3] (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[4]. The AESO will specify the location of PCC in functional specification on the project basis.
- **Point of connection** (POC), as used in this document, has the same meaning as defined in the AESO's CADG for use in the Alberta Reliability Standards (ARS). For most circumstances in this document, it is assumed the TCDC has a single POC. The AESO will specify the location of POC in functional specification on the project basis.
- **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 with reactive dispatching in normal operations and is 300 MW per 30 minutes (10 MW/min). Note that Ramp30 is different than the 30-Minute Ramping Reserve (R30) being introduced in the Restructured Energy Market[5].
- **System Operating Limit (SOL)**, 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.

[3] The current value and rationale for MSDC is captured in AESO 2025 Reliability Requirements Roadmap.
[4] The appropriate adjustments will be made for facilities with more complex interfaces in their functional specifications.
[5] Restructured Energy Market Final Design, Aug. 2025. Available: https://www.aeso.ca/assets/REM/Restructured-Energy-Market-Final-Design.pdf.

3. ARS, ISO Rules and Functional Specifications

The Alberta Reliability Standards (ARS)[6] are Alberta versions of NERC/WECC reliability standards. ARS establish reliability outcomes that applicable entities must meet to support the reliable operation of the AIES.

ISO rules[7] are rules made by the AESO and approved by the AUC that set binding technical and market obligations on market participants. ISO rules:

- Allow the AESO to facilitate the safe, reliable and economic operation of the AIES.
- Support a fair, efficient, and openly competitive market.

TCDCs must meet applicable requirements in ISO rules and ARS to safely and reliably connect to the AIES. If a TCDC proposes BTF generation, that generation must also meet all ISO rules and ARS requirements applicable to generating facilities. These ISO rules and ARS apply to:

- Transmission facilities
- Transmission-connected generators
- Transmission-connected aggregated generating facilities
- Transmission-connected energy storage facilities

The AESO may specify compliance with these requirements within the Functional Specification.

The AESO utilizes Functional Specifications to ensure that connections do not impact the safety and reliability of the grid. Functional Specifications are tailored to the individual characteristics of a TCDC to mitigate the unique risks associated with the connection.

TCDCs can expect to see the requirements and mitigations set out in this document being implemented into their Functional Specifications to ensure that they connect reliably.

In March 2026, NERC began developing new reliability standards for TCDCs[8]. The AESO plans to adopt similar standards after consulting with Alberta stakeholders and receiving approval from the Alberta Utilities Commission (AUC). Once approved, TCDC developers will be required to follow these standards.

4. TCDC Characteristics

TCDCs impact the Alberta grid in different ways depending on their facility design, internal facility processes and applications (e.g., crypto mining, high performance computing, artificial intelligence, etc.).

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[6] https://www.aeso.ca/rules-standards-and-tariff/alberta-reliability-standards/complete-set-of-standards/.

[7] https://www.aeso.ca/rules-standards-and-tariff/iso-rules/complete-set-of-iso-rules/.

[8] https://www.nerc.com/standards/reliability-standards-under-development/2026-02-computational-loads/.

To ensure reliable transmission system planning and operation of the AIES, the AESO requires consistent and detailed infrastructure and operating information for developing the connection of TCDCs. This information must accurately represent the design and operational characteristics of each facility, as it will be used in studies to model TCDC behaviour under both normal operating conditions and system disturbances. This information ensures studies accurately reflect how a TCDC behaves under both normal and abnormal conditions.

Unlike traditional loads such as residential, commercial, or industrial, TCDCs exhibit distinct electrical and consumption characteristics that can materially affect power quality, reliability and grid stability. Planning and operational studies require detailed models of TCDC behaviour, particularly their active and reactive power responses during voltage or frequency excursions, rather than relying on simplified or generic assumptions.

TCDCs vary in size, but many are significantly larger than many conventional loads. Therefore, understanding their composition is essential for power flow and dynamic simulations. This includes:

- Server loads
- Cooling/heating systems
- Auxiliary loads

Collaborative information sharing improves connection studies, system planning and real-time operations. To support accurate modelling in AESO studies, TCDCs will be required complete the *Data Centre Technical and Operating Characteristics* questionnaire.

The AESO focuses on details that can influence its power flow models, dynamic models (in both EMT and phasor domains), or that would materially change the load behaviour at the POC. Table 4-1 outlines key items from the questionnaire and indicates the stage of the connection process when each item is required.

Key Requirements for Data Centres During the Connection Process:

1. Provide the items listed in Table 4-1 at the indicated stage of the connection process.
2. Submit a Project Change Proposal (PCP) if any project details change before energization. This is consistent with the connection process.

After Energization

3. Notify the AESO of facility changes that could affect interactions with the AIES at the POC[9].
4. Submit a System Access Service Request (SASR) and provide all required materials to the AESO at least 100 days before implementing facility changes, including but not limited to:
   - Updates that influence dynamic behaviour

[9] Examples of changes that may affect the interaction of the TCDC with the AIES at the POC are changes in the load profile and facility design, internal outages, upgrade/replacement of the equipment that impacts the ride-through capability or dynamic behaviour of the TCDC.

- Load characteristics
  - Other fundamental design elements
5. To keep planning and operational needs aligned with actual performance, the AESO may request additional information from the facility, including:
   - Actual load profile
   - Temperature-sensitivity curve
   - Power Usage Effectiveness (PUE)
   - Single-line diagram
   - Operating characteristics
6. Requested information is to be provided within 30 days of the request so system models remain current.

Table 4-1: Summary of 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
Power Flow and Sequence Data File	RAW and SEQ PSS®E input data files representing TCDC performance to steady state and short circuit analysis	1
Transmission Reliability Requirement	Confirm whether a specific transmission reliability requirement exists (e.g., multi-circuit connection)	1
Electrical Single-Line Diagram	Submit a single-line diagram (SLD) as per AESO's SLD Guideline for Projects for AESO's review and acceptance. At this stage, the SLD can include the high-voltage (HV) equipment. Details for the medium-voltage (MV) equipment can be sent in Stage 2.	1

	Refer to Appendix A for more information	
Behind-the-Fence Generation	Submit the following information about BTF generation: • Number • Type • Capacity	1
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 following information: • 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[10] distribution system single-line diagram for AESO's review and acceptance. Refer to Appendix A for more information	2
Voltage Levels and Redundancy Configuration	Provide voltage levels throughout the TCDC and the redundancy configuration (e.g., N, N+1, 2N)	2
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	2

[10] 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 one kV to 35kV.

	Pumps, etc.	
Load Segmentation with Backup/UPS	Describe how internal loads are divided between UPS systems and backup generation	2
Dynamic File	DYR PSS®E input file representing the facility to perform transient studies (phase domain)	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 including applicable voltage/frequency thresholds, measurement type (e.g., Line to Line or Line to Neutral voltage) and location of measurement (e.g., on system side or lower voltage buses)	3

5. Facility Design

5.1 Transmission and Substation Design

Impacts on the AIES

TCDCs can pose risks to bulk system reliability due to the limited system capability to withstand the sudden loss of large demand blocks. If not adequately managed, abrupt reductions in internal demand beyond Most Severe Demand Contingency (MSDC) could lead to adverse impacts described below.

Current System Capability

Most Severe Demand Contingency (MSDC)

- MSDC represents the maximum single demand loss the AIES can accommodate while respecting the AC intertie out-rush margin, as defined in the AESO's R3[11].
- To ensure reliable operation of the AIES, the design of the data centre facility, its connection, and operation must take MSDC limitations into account, as discussed in *Requirements*, below.

Interties

- Any sudden load loss in the AIES results in an intertie out-rush approximately equal to the size of the load loss.
- Excessive power outflows on Alberta's AC interties, potentially exceeding their thermal or voltage stability limits, may result in load loss or cascading outages in violation of ARS.

Over-frequency excursions

- A significant and sudden drop in load may overload and trip the interties with large export. With limited inertia and primary frequency response, over-frequency excursions above the nominal 60 Hz will then likely occur.
- Over-frequency excursions may trigger the unplanned trip of generation in Alberta. This event can lead to frequency and voltage instability and may result in further cascading tripping of load and generation in violation of ARS.

Redundancy

- AESO planning practices assume that the transmission system in the area can integrate the TCDC in accordance with fundamental design principles, including redundancy of major equipment in the substation and transmission lines based on the MSDC limit, ramp-rate limits, power factor and applicable system operating limits (SOLs).
- Specific redundancy requirements for the transmission system will be determined separately on a case-by-case basis.

Contingency Planning

- The number of circuits and transformers and their capacity should be established with consideration of the MSDC limit, AIES ramp limitations, and the applicable SOLs and methodologies (e.g., FAC-011[12]).

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[11] AESO Reliability Requirements Roadmap, Aug. 2025. Available: https://www.aeso.ca/assets/Uploads/future-of-electricity/AESO-2025-Reliability-Requirements-Roadmap.pdf.
[12] System Operating Limit Methodology is documented in FAC-011's supporting document titled "*System Operating Limit Methodology for Operations Horizon*" (https://www.aeso.ca/assets/documents/SOL-Methodology-for-Operations-Horizon-FAC-011.pdf).

- Following a contingency, if a SOL is exceeded in real time, the AESO will bring the system back within limits in 30 minutes or less to prepare for the next contingency. This may include curtailment or shedding of TCDC load.
- SOLs are to be equal to the applicable Facility Ratings, system voltage limits, voltage stability limits, MSDC threshold and transient stability limits. The most limiting of these will determine the SOL used in real-time operations.

Requirements

TCDCs can expect the following requirements to form part of their functional specification to address the risks identified above. The specific solution proposed by a TCDC to address these risks will be reviewed by the AESO.

Facility Design

1. The TCDC will be required to submit the electrical SLD of the facility and the connection, including the medium-voltage distribution, to the AESO for review.
2. The facility, including the facility's medium-voltage distribution system, its substation, and the transmission connection, should be designed so that no single credible electric system event, including an internal breaker fault, results in net load loss at the POC that exceeds the MSDC for the TCDC facility.
3. The facility will be required to mitigate its loss of load for any non-electric system event that causes a loss of load greater than the MSDC.

Substation Design

4. The substation design to serve TCDCs will be required to avoid simple-bus or ring-bus configurations where they would result in fault clearing that trips load above the MSDC at the POC.
   - Alternative configurations must be selected to maintain compliance with the MSDC under credible events, including internal breaker fault scenarios.
   - TCDCs with DTS above the MSDC threshold are expected to use more than one circuit and transformer.
5. Where parallel transformers supply part or all the TCDC load, each transformer will be required to terminate on a separate breaker diameter to ensure that an internal breaker fault event does not trip more than the MSDC.

Circuit Design

6. When multiple circuits from a single system substation supply the TCDC load that exceeds the MSDC, each circuit will be required to terminate on a separate breaker diameter to ensure that an internal breaker fault event does not trip more than the MSDC at the POC.
7. For TCDCs served by multiple circuits, the AESO will assess cascade risk for events such as double-circuit tower failure and, considering the reliability needs of the TCDC, may require

circuits to be built on separate structures or rights-of-way. When deciding whether to separate circuits, the AESO will give consideration to:

– Overall system reliability
– The TCDC facility's criticality and impact
– TCDC load size
– Feasible routing options
– Potential transmission line crossings
– Line length

T-Tap Connections

8. T-tap connection alternatives may be considered if:
   – They meet the TCDC's reliability requirements and are supported by connection studies and protection & control (P&C) assessments.
   – The total load tripped on the main circuit and t-tap line due to a single contingency remains below the MSDC limit.

Planned Maintenance and Outage

9. The facility owner and the AESO will need to incorporate planned maintenance and other credible outage scenarios into the design and assess whether advanced protection schemes or temporary curtailment strategies are needed to maintain reliability during such conditions.

Future Planning

10. The facility owner and the AESO will need to account for future planned projects in the area when determining minimum circuit capacity so that staging and expansion can be managed prudently.

Illustrative Example

Tables 5-1 and 5-2 provide examples of the number of circuits and corresponding capacity requirements for transmission lines and transformers.

Example Scenario:

- TCDC Load: 800 MW
- Power Factor: 0.98
- MSDC: 200 MW
- AESO Ramp-Down Limit: 10 MW per minute (300 MW within 30 minutes)
- Required Transmission Lines: 3
- Minimum Line Rating: 510 MVA
- Planning Condition: Incorporates N-1-1 contingency planning

Considerations

- With three circuits in service, each 510 MVA line carries approximately 267 MW (i.e., the 800 MW load is divided among three circuits).
- Under an N-1 contingency, the two remaining circuits will each carry 400 MW each (approximately 408 MVA).
- To prepare for the next contingency (N-1-1), 300 MW of load must be reduced within 30 minutes so the system can continue to operate securely with only two circuits in service.
- Under this condition, the two remaining circuits would carry 500 MW (approximately 510 MVA). The 30-minute ramping window prescribed by the SOL also ensures that, should the remaining circuits be lost, no more than the MSDC (200 MW) would be dropped.

This is only an illustrative example. Factors such as facility power factor, available conductor sizes, substation configuration, and other design parameters can influence the final transmission sizing.

The AESO will support the TCDC throughout the detailed design process to ensure that MSDC considerations are appropriately incorporated.

Table 5-1: 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	204.1	MSDC	0
500	2	510.2	MSDC + Ramp30	200
800	3	510.2	MSDC + 2 x Ramp30	500
1000	3	1020.4	N-2 Design (large circuit capacity)	500
1000	4	510.2	N-2 Design (small circuit capacity)	800
2000	4	1020.4	N-2 Design (large circuit capacity)	1000
Assuming: MSDC = 200 MW; PF = 0.98; Ramp30= 300 MW (30 Min×10 MW/Min)				

Table 5-2: Example of Transformer Quantity and Capacity for a portion of TCDC

Parallel Transformer Capacity Limit (MW) [Limitation]				
Transformer Rating ->	Transformer Size 150 MVA (147 MW)	Transformer Size 225 MVA (220.5 MW)	Transformer Size 300 MVA (294 MW)	Transformer Size 400 MVA (392 MW)
1	161.7 MW [147 MW x Emergency Ratio]	200 MW [MSDC]	200 MW [MSDC]	200 MW [MSDC]
2	161.7 MW [147 MW x Emergency Ratio]	242.6 MW [220.5 MW x Emergency Ratio]	323.4 MW [294 MW x Emergency Ratio]	431.2 MW [392 MW x Emergency Ratio]
3	323.4 MW [2 x 147 MW x Emergency Ratio]	485.1 MW [2 x 220.5 MW x Emergency Ratio]	646.8 MW [2 x 294 MW x Emergency Ratio]	800 MW [MSDC + 2 x Ramp30]
4	485.1 MW [3 x 147 MW x Emergency Ratio]	727.7 MW [3 x 220.5 MW x Emergency Ratio]	800 MW [MSDC + 2 x Ramp30]	N/A
Assuming: MSDC = 200 MW; PF = 0.98; Transformer Emergency Ratio 110%; Ramp30= 300 MW (30 Min×10 MW/Min)				

Potential Mitigations

- Ensuring that the TCDC's flexibility in ramping-down capability can adequately prepare the system for the next contingency while still satisfying the MSDC requirement.
- Limited ramp up and down controllability may necessitate additional redundancy to avoid exceeding the MSDC limit following a contingency or outage and any subsequent fault.
- The AESO will work with the TCDC during facility design to better understand their intended mechanism to meet the MSDC requirement, for example, through hardware redundancy, or improved ramp controllability, or a hybrid solution.

5.2 Emergency Back-up Design

TCDC facility owner may include emergency backup generation to support high-uptime requirements of their facility, depending on the design and application.

Impacts on the AIES

- If emergency back-up generation synchronizes with the AIES under any circumstances, even with zero STS, it effectively behaves as a grid-connected generator and interacts with the AIES.

- Such unstudied synchronization introduces unmodelled generator response to the grid disturbances, which can cause instabilities.

Requirements

1. 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.
2. Mechanical interlocks must be designed to prevent the synchronization of on-site emergency backup generation to the grid.
3. Any generator that intends to synchronize to the grid must follow the Generation Connection Process and complete all applicable technical studies. All relevant ISO Rules and Alberta Reliability Standards (ARS) applicable to generating units applies to such generators.

5.3 Reactive Power Capability

Reactive power capability is essential to maintain acceptable voltage levels and ensure stable operation of the power system under normal and contingency conditions. TCDCs are typically much larger than conventional loads and can, particularly during rapid load changes, have a material impact on local voltage performance. Adequate reactive power capability ensures that large transmission-connected loads manage their own reactive demand and do not degrade voltage performance or compromise overall grid reliability.

Impacts on the AIES

Excessive reactive power drawn by a TCDC may result in ARS violations and depletion of available reactive power resources. This increases system vulnerability to local disturbances, where sudden operating changes can lead to severe low voltage conditions and potential tripping of loads or generation or both. Uncontrolled load or generation tripping can result in large and sudden changes in system power balance, potentially leading to trip of intertie and frequency excursions and reduced system stability in violation of ARS.

Requirements

1. The TCDC will be required to design the load facility with reactive power resources to result in a power factor of above 0.98 lagging.
2. Additional reactive capability might be required and will be determined by connection studies with the objectives:
   - Connection of the TCDC will not degrade voltage stability in the area under normal and N-1 conditions.
   - Voltage deviation under maximum ramp rate must remain within the rapid voltage change limit of Section 503.11 of ISO Rules.
3. The connection study will indicate:
   - MVAr of reactive compensation needed
   - Switched reactive components

- Dynamic reactive components
- Location and control point of the reactive system

4. Reactive power requirement for full operations under system outage conditions (N-1-1) will be identified as an option for TCDC to avoid operational curtailment under outage conditions.
5. Reactive power compensation could be behind-the-fence or on the transmission system.

5.4 Protection and Control

Protection requirements serve three functions:

- Ensure that faults can be rapidly detected and isolated.
- Ensure system operators maintain supervisory control over high-voltage equipment at the TCDC and disconnect TCDC facilities, if necessary, during system emergencies.
- Ensure proper grounding and surge protection practices are in place to protect both the facility and the grid.

Together, these requirements provide the foundational electrical protection, switching and grounding integrity needed to prevent mis-operations, safely manage contingencies and maintain stable grid performance.

Requirements

Protection and Control

1. Protection and control requirements for 100 kV and above must follow Section 503.15 of the ISO rules.
2. Due to complex fault and emergency scenarios, such as generator failures or grid supply loss, the AESO may require hardware in the loop (HIL) testing of transmission line protections. Where the transmission line protections are owned by the TFO, the TFO must perform the HIL testing and validate all associated relay settings.

Isolating and Interrupting Devices

3. Isolating and interrupting device requirements outlined in Section 503.10 of the ISO rules must be followed.
4. The legal owner of a transmission facility may be required to have supervisory control to open the high-voltage breaker(s) at the TCDC if applicable.

Grounding and Surge Protection

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

5.5 Monitoring

TCDC facilities will be required to provide timely and accurate measurement data to the AESO's system control centre for different quantities and resolutions, including:

- Voltage
- Current
- Frequency
- Harmonics
- Dynamic load changes

Monitoring devices such as SCADA and synchrophasor measurement system (PMU) enable the AESO to:

- Observe real-time system conditions
- Assess compliance with ISO rules
- Respond to abnormal events

Other monitoring devices such as digital fault recorders (DFRs) and power quality meters provide valuable data for offline event analysis to help assess compliance to ISO rules and support possible mitigation measures.

Illustrative Example

Figure 5-1 shows the 1 Hz oscillations along with 11 Hz well-damped ringdowns that were observed from PMU data on two adjacent substations[13]. Without sufficient PMU data from the neighbouring substations, it would have been difficult to find the loads that were the root cause of such oscillations.

[13] NERC, Characteristics and Risks of Emerging Large Loads. Atlanta, GA, USA: NERC, Jul. 2025.

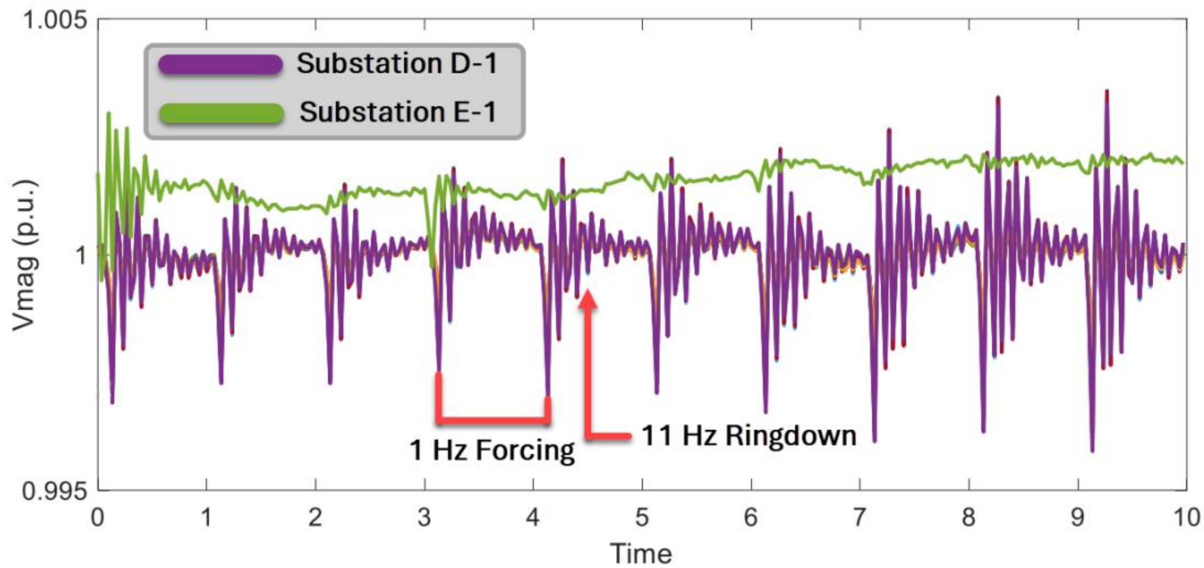

Figure 5-1: Example of 1 Hz Oscillation along with well-damped 11 Hz ringdown at the Point of Connection of a Data Centre

Challenges with TCDCs

Data centres can exhibit:

- High-frequency oscillations
- Rapid load ramping
- Significant power electronics activity

These factors can impact power quality and system stability. In several jurisdictions, the absence of adequate monitoring devices has hindered the identification of disturbance sources and delayed post-event analysis, limiting the ability to implement corrective actions and improve system reliability.

Impacts on the AIES

Lack of real-time visibility and control

Without robust telecommunication, SCADA and voice communications, AESO system controllers:

- Lack real-time visibility and controllability of large loads
- Have limited ability to accurately characterize TCDC operating states, monitor rapid changes in demand and effectively respond to abnormal system conditions

Delayed or missing information in fast-evolving events can create system reliability issues due to:

- Preventing timely corrective actions
- Increasing the risk of cascading impacts

Lack of high-resolution measurement data

A lack of high-resolution measurement data, such as from Phasor Measurement Units (PMUs), significantly reduces system observability during dynamic events. PMUs provide time-synchronized measurements in fractions of a second that are critical for understanding fast frequency, voltage, and angle dynamics, particularly in a relatively small and weakly interconnected system like the AIES.

Without PMU data:

- Operators and planners must rely on lower-resolution sampling over seconds of SCADA measurements, which is insufficient to capture some system responses.
- Sub-synchronous oscillations may go undetected, posing reliability risks.
  - PMUs can assist in identifying sub-synchronous oscillations, which may excite torsional or inter-area modes by providing tens of samples per second. If these oscillations are not addressed in a timely fashion, they can lead to reliability risks.
  - PMUs align with industry best practices in grid monitoring and reliability management.

Digital Fault Recorders (DFR)s

DFRs provide detailed waveform data essential for:

- Identifying the root cause of disturbances
- Validating system models
- Distinguishing between load-side, network-side, or protection-related issues.

Without DFR data:

- Forensic analysis depth and accuracy is limited
- Investigation timelines lengthen
- Opportunities to learn actionable lessons from events and improve system reliability are missed
- The likelihood of repeat issues increases

Power quality monitoring

Some TCDCs, depending on size and location of the facility, can be significant sources of power quality issues due to:

- Rapid load ramping
- High-frequency oscillations
- Extensive use of power electronics that impose harmonic waveforms on the electric grid

Without dedicated power quality monitoring devices:

- Identifying the source of these issues becomes challenging
- TCDCs may struggle to comply with Section 503.11 (Power Quality) of the ISO Rules.

Overall, the lack of adequate telecom, SCADA, PMU, DFR, and power quality monitoring capabilities:

- Adversely impacts real-time operation
- Weakens event analysis
- Reduces confidence in system studies and mitigation measures
- Increases the real time reliability risk posed by large, dynamic loads like TCDCs

Requirements

Telecommunications

1. TCDC facilities with load greater than or equal to 500 MW, will be required to have physically diverse tele-protection grade telecommunication infrastructure links to the AIES[14].

SCADA

2. TCDC facilities SCADA may be required to provide analog and status points for all high-voltage and medium-voltage equipment and buses.
3. TCDC facilities with load greater than or equal to 300 MW will be required two SCADA telecommunication paths to the AESO, with one using the Utility Telecom Network (UTN) and the other using a commercial network.

VOICE

4. Each TCDC facility operator may be required to have a primary voice communication capability for the purposes of communication with the ISO and its operator of a transmission facility that is:
   - A direct access telephone on the public telephone network.
   - Not degraded by any other communication functionality or any other data transfer activities if there is any shared equipment.

Digital Fault Recorders

5. The TCDC may be required to have DFRs installed.
6. The requirements for DFRs will be required to follow sequence of event recording and fault recording data requirements in PRC-002-AB-2.
7. DFRs must record voltages and currents at POC for elements (line and/or transformers) connected to the TCDC facility.

[14] The loss of critical services and real-time visibility (e.g., line protection, remedial action schemes, SCADA, and status information) for TCDCs pose an increasing operational and reliability risk to the power system as they increase in size. Given the scale of these facilities, loss of communications can impair system operators' ability to monitor conditions, respond to disturbances, and take timely corrective actions. Similar redundancy and diversity requirements are currently applied to critical system elements, such as 500 kV transmission lines.

Synchrophasor measurement system

8. The synchrophasor measurement system requirements will need to meet the functionality requirements, data requirements, data format requirements and communication requirements set out in IEEE Standards C37.118.1a–2014 and C37.118.2-2011.
9. Synchrophasor measurement devices will record voltages and currents at POC for elements (line and/or transformers) connected to the TCDC facility.
10. The synchrophasor measurements will need to stream to both the AESO's primary control centre and the AESO's backup control centre.
11. The synchrophasor measurements devices will be required to be capable of streaming the data with the sample rate of at least 30 samples/seconds. The AESO may specify a higher sample rate of up to 120 samples/seconds based on reliability needs and its technical considerations on a case-by-case basis in functional specifications.

Power Quality

12. Power quality monitors may be required to demonstrate compliance with *IEC 61000430*.
13. Power quality monitoring devices will be installed on the high voltage bus at the POC substations (including switching station and all load substations) and owned by the TFO.
14. Power quality monitors will capture supply voltage interruptions, dips and swells, both harmonics and inter-harmonics and sub-synchronous oscillations.
15. To establish baseline characteristics and demonstrate initial compliance, the TFO in coordination with the TCDC facility owner will provide power quality measurements at the PCC 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.
16. The data requirements for power quality monitors will be similar to Disturbance Monitoring and Reporting Requirements PRC-002-AB-2, requirements R11.1 and R11.2.
17. Compliance with power quality requirements is a continuous obligation throughout the operational life of the facility. Should incompliance to Section 503.11 (Power Quality) of the ISO Rules arise at any point, the TCDC must investigate the issue and implement mitigation measures.

6. Disturbance Response

6.1 Ride-Through Capability

Ride-through capability is the ability of a load to remain connected to the power system and continue drawing power during short-duration transmission faults and disturbances, even while voltage, frequency, or both deviate from normal levels.

Data centres are highly sensitive to transmission system faults and disturbances, particularly those affecting voltage. In cases from other jurisdictions, insufficient ride-through capability of data centres caused load tripping during normally cleared transmission faults, contributing to wider system reliability issues[15,16].

Impact on the AIES

- The AIES is weakly interconnected with the Western Interconnection and can become islanded, either intentionally or unintentionally, resulting in limited system-level frequency stability.
  - Under these conditions, frequency ride-through capability of TCDCs is critical to maintain system stability.
- The AIES is relatively small with a peak load of approximately 12,785 MW (recorded on December 11, 2025).
  - The sudden reduction or loss of large data-centre load outside of defined frequency ride-through envelopes can significantly exacerbate frequency disturbances.
- The AIES is characterized by low system strength in certain areas, making voltage ride-through capability equally critical to prevent the TCDC from unnecessary tripping.
- If the resulting load reduction is sufficiently large, the load-generation imbalance may cause the AB-BC intertie to trip, forcing the AIES into an unplanned islanding condition.
- Frequency deviations following a loss of load or generation are more severe in the AIES than in larger systems that benefit from stronger primary frequency response.

Current System Capabilities

Per ARS requirements, under-frequency events with the AIES are mitigated through an established Under Frequency Load Shed (UFLS) program. The AIES currently has no equivalent protection for over-frequency events. As a result:

- Unexpected load or intertie losses during periods of high exports could trigger generator over-frequency protection and lead to cascading outages of generators.
- Unmanaged cascading tripping on generators may lead to blackout.

Requirements

1. Unless stated otherwise, the applicable voltage and frequency outlined are at the POC, and per unit (p.u) voltages are based on the nominal voltage at the POC.
2. Facility owners will be required to design the entire TCDC, including its auxiliary systems, to meet the ride-through requirements specified in this section.

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[15] NERC, Incident Review: Considering Simultaneous Voltage-Sensitive Load Reductions, Atlanta, GA, USA, Event Analysis Rep., Jan. 8, 2025.
[16] ERCOT, NOGRR282: Large Electronic Load Ride-Through Requirements and NPRR1308, Item 6.2, ERCOT Board of Directors Meeting, Austin, TX, USA, Dec. 1, 2025.

3. For TCDCs which are having challenges meeting the proposed ride-through capability, the AESO may consider introducing an exemption process.
   – However, such requests require detailed technical studies to demonstrate that insufficient ride-through capability does not result in adverse reliability impacts on the system, which could otherwise affect project timelines. Where reliability impacts are identified, appropriate mitigation measures will be explored at both the facility level and the system level.

Voltage Measurement Requirements:

4. Voltage will be measured with ± 2.5 percent measurement accuracy in the range of 0.1 to 2.0 p.u. of the nominal voltage.
5. 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:

6. Frequency will 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 percent of the nominal positive-sequence voltage.
7. Frequency will be measured over a time period (typically 3-6 cycles) to calculate system frequency at the POC.
8. Instantaneous or single points of measurement should not be used in the determination of protection settings.

Protection Settings and Ride-Through Compliance Requirements:

9. 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.) should be based on equipment capability.
10. The boundary of ride-through envelopes should not be interpreted as a must-trip requirement.
11. The TCDC will need to provide setting reports to the AESO, including original equipment manufacturer (OEM) capability curves to demonstrate that the TCDC protection settings are properly determined.

Backup Generation Requirements:

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

Low- and High-Voltage Ride-Through Requirements:

13. The TCDC will be required to ride through voltage disturbances of the magnitude and duration specified in Table 6-1.

14. The TCDC should ride through multiple voltage deviations at the POC, 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 6-1: Low- and High-Voltage Ride-Through Requirements

Root-Mean Square (RMS) Voltage, V (pu)	Minimum Ride-Through Time (Seconds)[17]
V > 1.25	May ride through or may trip
1.15 < V ≤ 1.25	1
1.10 < V ≤ 1.15	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

15. The TCDC should not cease its current exchange with the transmission system and will be required not to trip due to self-protection for disturbances that originate outside the facility, as described in Table 6-1.
    - Momentary cessation, including change over to TCDC internal sources like batteries or back-up generation, is not allowed within the ride-through envelope, as described in Table 6-1.
16. The TCDC will be required to use constant current control as seen at the POC and must not use constant power level control during ride-through.
17. During a ride-through event, and if the capability exists within the TCDC facility, priority should 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.

[17] 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.

Restore Output After Voltage Ride-Through:

18. After the voltage at the POC returns to the continuous operation region per Table 6-1Table , the TCDC should restore active power consumption to 100 percent of the pre-disturbance level within 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[18].
19. The default active power recovery time is within one 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.
    - This should be captured as part of System Strength assessment, which is part of TCDC connection studies.

System Impact Assessment for Voltage-Ride-Through:

20. The system impact due to transmission faults and voltage ride-through behaviour of the TCDC should be captured as part of Phasor Domain Transient Stability, which is part of TCDC connection studies. This includes assessing impacts on local area voltages, potential inter-tie tripping and system frequency. Mitigation measures, if required, should be developed and implemented based on study results.

Transient Overvoltage Ride-Through:

21. The TCDC will be required to ride through transient overvoltage of the magnitude and duration specified in Table 6-2.
    - The voltages in Table 6-2 are the greater of individual phase-to-phase or phase-to-ground instantaneous voltages.
22. During the transient overvoltage ride-through, the TCDC will be required to maintain its pre-disturbance active and reactive power consumption.
    - It does not have to respond to transient overvoltage, i.e., enter reactive current priority mode and/or change the magnitude of current output.

[18] For example, a TCDC facility with the total of 500 MW contracted DTS and/or DOS load and one second active power recovery time must restore its power to the pre-disturbance level at the average rate of 500 MW per second.

Table 6-2: Transient Overvoltage Ride-Through Requirements

Instantaneous Phase-to-Phase or Phase-to-Ground Voltage, V (pu)	Minimum Ride-Through Time (milliseconds)[19]
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

Low- and High-Frequency Ride-Through Requirements:

23. The TCDC will be required to ride through frequency disturbances of the magnitude and duration specified in Table 6-3.
24. The TCDC should maintain pre-disturbance active and reactive power consumption during the frequency ride-through.

Table 6-3: 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

Rate of Change of Frequency Ride-Through Requirements:

25. Within the frequency ride-through range per Table 6-3, the TCDC will be required to 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.

[19] 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.

26. RoCoF will be calculated as the average rate of change of frequency over a rolling 0.5 second averaging window.
27. The TCDC should maintain pre-disturbance active and reactive power consumption during the RoCoF ride-through event.

Voltage Phase Angle Jump Ride-Through Requirements:

28. The TCDC will be required to ride through positive-sequence phase angle changes within a sub-cycle-to-cycle time frame of the RMS voltage at the POC of less than or equal to 25 electrical degrees.
29. The TCDC should 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.
30. The TCDC will be required to maintain pre-disturbance active and reactive power consumption during the voltage phase angle jump ride-through.

Volts per Hz (V/Hz) Ride-Through Requirements:

31. The TCDC will be required to ride through grid disturbances with V/Hz, measured at the POC, of at least 1.1 per unit for 45 seconds and 1.18 per unit for two seconds.
32. The TCDC should maintain pre-disturbance active and reactive power consumption during the V/Hz ride-through.

Potential Mitigations

- Data centres can employ different technologies and architectures, resulting in varying ride-through capabilities.

Double-Conversion UPS

- Provides some of the highest ride-through capabilities due to the high controllability of the UPS.
- Acts as an effective interface between the AIES and the electronic loads.

Single-Conversion UPS

- Converts AC power to DC, with GPU racks relying on batteries for backup.
- Provides less isolation between the electronic loads and the grid.
  - As a result, these loads are more exposed to grid disturbances and are therefore more susceptible to voltage and frequency events.

Rotary UPS

- Combine fast-acting energy storage (e.g., flywheels) with thermal backup generators.
- Storage provides very short-term power to the electronic loads until the thermal generators start.
  - Once the thermal generators are online, transferring the load back to the grid is not immediate and is often performed manually.

- Limit the ability of the data centre to quickly restore normal grid-connected operation following a transient disturbance[20].

Equipment and configuration changes

- In some cases, a TCDC may be able to meet HVRT requirements through appropriate mitigations such as:
  - Adequately sized surge arrestors.
  - Selecting tap settings on main power transformers, thereby avoiding the need to uprate lower-voltage equipment (e.g., 34.5 kV and below).
  - The selection of tap position must also meet other relevant requirements such as low voltage ride through and reactive power requirements through appropriate studies.

Although not yet widely commercialized for TCDCs, hardware-based solutions such as grid-forming battery energy storage systems (GFM BESS) and FACTS devices, including E-STATCOMs, have the potential to mitigate voltage dip issues and address IT equipment limitations related to LVRT and HVRT. Several vendors have presented such solutions to NERC and ESIG [21, 22, 23].

Reactive power support

- Devices, such as STATCOMs, SVCs, or synchronous condensers installed at either the facility or system level can further help alleviate LVRT and HVRT issues.
- Such devices will be more effective at the facility level.
  - Reactive power support devices located on the system side do not fully address LVRT requirements when there is a bus fault or close-in line fault on the system side.

Potential operational measures

- As a potential mitigation measure to maintain system reliability, special protection schemes might be considered which involve automatic adjustments of active power from the resources in the system. However, the feasibility and effectiveness of such solutions are highly dependent on the:
  - Data centre's specific characteristics
  - Nature and severity of the ride-through deficiencies
  - Availability and suitability of resources that could be included in a scheme.

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[20] NERC, Incident Review: Considering Simultaneous Voltage-Sensitive Load Reductions, Atlanta, GA, USA, Event Analysis Rep., Jan. 8, 2025.

[21] NERC, Grid-Forming Technology: Bulk Power System Reliability Considerations, North American Electric Reliability Corporation, Atlanta, GA, USA, White Paper, Dec. 2021.

[22] Energy Systems Integration Group (ESIG), Grid-Forming Technology in Energy Systems Integration, Reston, VA, USA, Rep., Mar. 2022.

[23] NERC, LLTF April Meeting & Technical Workshop Presentations, Large Loads Task Force (LLTF), Atlanta, GA, USA, Apr. 10, 2025.

6.2 Under Voltage Load Shedding (UVLS) and Under Frequency Load Shedding (UFLS)

UFLS is an automatic load shedding program designed to arrest system frequency decline following a significant imbalance between generation and load within AIES. UFLS are:

- Typically implemented in stages based on predefined frequency thresholds.
- Considered a key defense mechanism for maintaining system stability and preventing widespread system collapse.

UVLS is an automatic load shedding program that is activated in response to sustained low voltage conditions in specific areas of the power system. It's intended to mitigate voltage instability or voltage collapse by reducing load when other voltage control measures are insufficient.

TCDCs play a key role in ensuring sufficient UFLS and UVLS capability is available to support overall grid reliability. All DTS-contracted loads in Alberta including TCDCs must be capable of participating in UVLS and UFLS systems[24].

Impacts on the AIES

UFLS and UVLS are critical last-line defence mechanisms for maintaining system stability during severe frequency and voltage events. If participation in either scheme is insufficient:

- System reliability declines.
- The AESO's ability to meet applicable reliability standards (e.g., PRC-006-AB-3 and PRC-010-AB-2) is reduced.
- The risk of widespread system collapse following significant load-generation imbalance or voltage instability increases.

Participation in UFLS and/or UVLS, once identified by AESO and/or WECC, is a mandatory reliability requirement and not a voluntary service.

- Participation requirements for UFLS and UVLS programs are primarily about ensuring the availability of preconfigured load-shedding capability for rare, high severity events, rather than routine curtailment.
- During sufficiently severe under-frequency or under-voltage disturbances, a facility may still inherently or due to facility protection systems reduce consumption or disconnect as a response to system conditions
  - This results in a reduction of net load at the POC regardless of whether the facility is enrolled in UFLS/UVLS.

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[24] As per PRC-006-AB-3 and PRC-AB-010-AB-2, all loads haves the responsibility to be capable of participating in UVLS and UFLS that the ISO established. ID #2021-002 provides the MPs with the existing Alberta UFLS program referred to in PRC-006-AB-3.

While a formal UVLS program is not currently in place, the availability of UVLS capability – either as a program or as part of a remedial action scheme – may be required based on TCDC study outcomes.

Current System Capabilities

The AIES uses several mechanisms to stabilize under-frequency after a disturbance:

System Inertia

- Provides the initial resistance to frequency change immediately following a disturbance.

Primary Frequency Response (PFR) from generator governors

- Helps arrest frequency deviations.

Fast Frequency Response (FFR)

- When armed, FFR can respond to provide rapid support during events such as sudden loss of imports from the Alberta–B.C. Intertie, the Montana–Alberta Tie Line, or internal generation trips.

If frequency continues to decline beyond these measures, the AIES relies on UFLS as a last-resort automatic protection scheme that operates at specified frequency thresholds, removes loads and maintains system frequency and reliability.

Requirements

1. Relays within the TCDCs will be required to be equipped with UFLS and UVLS. AESO will specify which breakers to have this provision in project FS.
2. The TCDC may be required to provide the capability to selectively trip a portion of its load up to its entire load for future UFLS and/or UVLS programs the ISO establishes.

Potential Mitigations

Data centres typically have multiple transformers and internal procedures to manage grid power usage.

To minimize the operational impact of UFLS or UVLS events on TCDC, a TCDC may be designed with additional backup capability (e.g., generators and/or battery storages).

Where a TCDC has limited UFLS capability, the AESO may assess whether UFLS participation can be limited while still maintaining AIES reliability.

7. Operations and Balancing

7.1 Oscillatory Behaviours

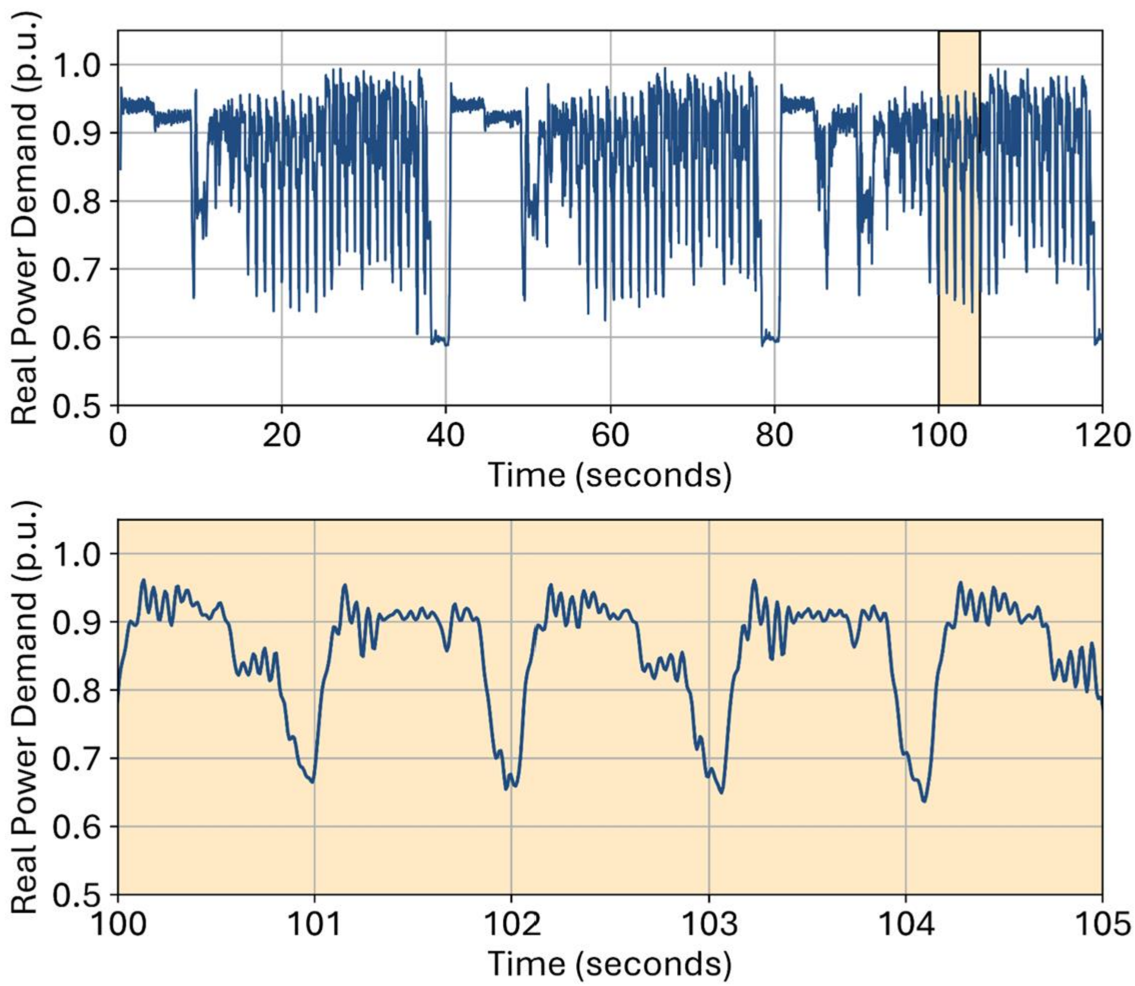
Oscillatory behaviours are swings in power demand that occur more frequently and with greater magnitude than conventional loads. Unlike other loads with stable, predictable consumption patterns, some data centres have oscillatory load profiles that can vary by a significant margin on a frequent (within seconds and minutes) and repeatable basis. Traditional mitigations, such as offsetting with conventional generators or storage resources, are too slow to handle oscillations, requiring alternate solutions.

Illustrative Example

AI training data centres operate in cycles, with most time spent on heavy computation. With each interval (i.e., oscillatory cycle), GPUs pause to coordinate or perform non-computational tasks, such as synchronizing model weights during all-reduce operations or writing checkpoints.

During compute-intensive phases, GPU power use can reach maximum levels. During coordination phases, it can drop close to idle. These rapid shifts cause large, fast power fluctuations.

Figure 7-1 below illustrates sub-minute oscillations during an AI training block[25].



[25] NERC, Characteristics and Risks of Emerging Large Loads. Atlanta, GA, USA: NERC, Jul. 2025.

Figure 7-1: Example AI Data Centre Load Profile During Training Over Two Minutes (Top) and a Five-Second Zoomed-on (Bottom)

Impacts on the AIES

The AIES is relatively small with limited interconnection with neighboring jurisdictions. Oscillatory behaviour of some data centre processes creates challenges for grid stability. The AIES is not large enough to absorb the size and frequency of load oscillations potentially created by data centre loads, which are instead transmitted over Alberta's synchronous interties. This leads to:

- Deviations from the scheduled intertie flow and frequency, and consequently large deviations in Area Control Error (ACE), and may trip the intertie in the worst case.
- Load induced oscillations on the electric grid.

When ACE deviates significantly from zero, it indicates a load-generation imbalance that can cause frequency deviations, potentially affecting interconnected systems across the Western Electricity Coordinating Council (WECC) and violating reliability standards[26]. In extreme cases, this imbalance can result in intertie tripping and is a serious reliability risk.

The rapid, uncoordinated load changes from data centres require an active response from the facility, whereby the oscillations are mitigated at the POC and system impact is minimized.

Key Impacts

Real Power (MW) Supply/Demand Imbalance

- Power generation can't respond fast enough to TCDC load oscillations.
- Transmission Reserve Margin (TRM), a component of intertie capacity that accommodates typical supply and demand imbalance on the Alberta grid is currently 65 MW[27] and is insufficient to accommodate data centre load oscillations.
- Under severe conditions, high amplitude load oscillations may cause intertie tripping, frequency instability, and potentially cascading generator outages within Alberta.

Voltage

- Rapid, frequent power consumption changes can disrupt voltage at the POC and nearby areas.
- This can result in non-compliance with ISO Rule Section 503.11 (Power Quality) and may lead to poor power quality (i.e., flicker) and, in extreme scenarios, grid instability.

Load-Induced and Control-Driven Oscillations

- Large data centres can introduce oscillatory risks via two key mechanisms:

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[26] ARS BAL-001-AB-2 Real Power Balancing Control Performance.

[27] Information Document Available Transfer Capability and Transfer Path Management ID #2011-001R

– Load-induced forced oscillations: rapid and frequent consumption changes drive forced oscillations.
– Control-driven oscillations: data centre's IT equipment, comprised largely of power electronics, that can cause unintended control interaction with the network, including other nearby device's controls.

The data centre may introduce new unstable or poorly damped oscillatory modes or adversely interact with existing critical oscillatory modes in the grid:

- Very low to low-frequency modes (e.g. 0.01–3 Hz)
  – Inter-area[28] and local electro-mechanical modes.
- **Control-interaction modes**
  – Interactions that can happen between internal control loops of multiple power electronic-based devices [e.g. inverter-based resource (IBRs), high-voltage direct current (HVDC), Flexible AC Transmission System (FACTS)] or interaction of these controls with the electrical network [e.g. series-compensated transmission lines].
- **Torsional frequency modes (e.g. 10-40 Hz)**
  – Mechanical shaft natural modes of turbine-generators that can be excited by interactions with the electrical network (e.g. series-compensated transmission lines) or nearby power-electronic based device's controls [e.g. HVDC].

These interactions may grow in magnitude, degrading system reliability, stressing equipment, or reducing power quality.

Current System Capabilities

The AESO routinely manages supply and demand variability on the AIES, which differs fundamentally from the oscillatory nature of some data centres. When supply and demand variability is low and infrequent, the AESO can maintain system reliability though:

- TRM of 65 MW that buffers the system against short-term variability such as sudden load changes.
- Current mechanisms to manage fast and frequent MW variability are limited, and the AIES is unable to accommodate the large variability in demand caused by the load oscillatory nature of some data centres.

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[28] In the Western Interconnection (WECC), which includes Alberta when interconnected, dominant inter-area electromechanical modes involving Alberta have been observed in the ~0.20–0.30 Hz range (North–South Mode A, with Alberta oscillating against the broader Western system) and in the ~0.35–0.45 Hz range (North–South Mode B, often referred to as an Alberta-associated mode, characterized by Alberta oscillating against British Columbia and the northern U.S., which in turn oscillate against the southern U.S).

Requirements

1. To mitigate oscillatory load behaviour and maintain bulk system reliability, TCDC load variations at the POC will be required to be managed and avoid impacts to system reliability.
2. To ensure real-power oscillations remain within AIES capability limits, the TCDC load will be required to limit real-power consumption to system-tolerable levels from a real-power imbalance perspective, in accordance with guidelines intended to be published by the AESO.
3. Voltage variations caused by oscillations should:
   - Be limited to the acceptable range provided in ISO Rule 503.11 (Power Quality).
   - Avoid causing load-induced forced oscillations[29].

Potential Mitigations

System-level solutions were explored, but have several limitations:

- Non-localized solutions may result in oscillation of voltage angle and impact nearby equipment.
- Have diminished ability to address a diverse set of oscillatory behaviours, compared to solutions customized for a site and its characteristics.
- Involves highly complex cost allocation.
- Typically require longer timeline than facility-level solutions and can negatively impact in-service dates.

To address the challenges stemming from oscillatory behaviour, data centres should consider the following:

- Complete studies to understand how the facility's behaviour will interact with the grid.
- If the power oscillations resulting in rapid voltage changes at the Point of Connection, explore solutions to reduce the power oscillations amplitude and frequency that bring the voltage changes within acceptable range, as defined in ISO Rule Section 501.11 (Power Quality).
- Complete facility-specific electromagnetic transient (EMT) studies to assess the risk of oscillations and control instability.
- In the event of risk of oscillations, explore solutions to mitigate oscillations and ensure stable operation.

While not exhaustive, the AESO understands there are a limited number of technical solutions available to market participants to help mitigate the impacts of oscillatory behaviour on the AIES.

- Hardware solutions, such as UPS-based data centre designs, can help present a smoother load profile at the POC.

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[29] Load induced forced oscillations are sustained power system oscillations caused by periodic disturbances injected into the grid originating from TCDCs rather than arising from the system's natural modes.

- Capacitor bank units, supercapacitors[30], dynamic voltage support devices (e.g. E-STATCOM), and appropriately sized grid forming battery energy storage systems (GFM-BESS) can support facilities manage power oscillations.
- Software-based mitigations, including GPU power-smoothing strategies (e.g., preset power profiles applied to each GPU)[31] can be combined with these hardware solutions to further moderate power consumption as seen at the POC.

7.2 Ramping

Ramp is the rate of change in real power consumption at POC measured over seconds to minutes.

Data centres can have:

- Infrequent energizing or de-energizing activities, with facility ramping from 0 MW to full contract DTS volume or ramping from full contract DTS volume to 0 MW.
  - This is typically associated with planned outages and in coordination with the AESO.
- Semi-frequent but rapid changes to the facility's steady-state power consumption level, which are distinct from the oscillatory behaviour discussed in Section 7.1.
  - The ramp in power consumption behaviour is typically associated with transitioning between the facility's normal operational modes, such as model training, fine-tuning, and inference.

Power consumption ramp events can create significant challenges for grid stability. Rapid changes in power consumption might cause voltage fluctuations. At the same time, power generation may not adjust at the same pace, particularly if the ramp is uncoordinated with the AESO, and can result in:

- Supply and demand imbalances
- Deviations from scheduled intertie flows
- Frequency and voltage excursions

The AIES has limited capability to manage these rapid changes, increasing the risk of operational issues during steep load ramps.

Illustrative Example:

Figure 7-2 shows similar steep up- and down-ramps at a 450-MW facility over a four-hour window.

In the event of an uncoordinated load ramp-up or ramp-down or load-gen imbalance, the initial power imbalance is automatically absorbed by Regulating Reserve (RR) through Automatic Generation Control (AGC) response.

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[30] J. F. Wasik, "Supercapacitors: Solving AI's Energy Spikes," *IEEE Spectrum*, Apr. 2024.
[31] E. Choukse et al., "Power Stabilization for AI Training Datacenters," arXiv preprint, arXiv:2508.14318, Aug. 2025.

For ramping events lasting several minutes:

- RR provides short-term balancing while system controllers actively dispatch energy market resources to replace the deployed regulating capacity and restore RR toward its neutral operating point.
- If RR is insufficient to manage an uncoordinated load ramp, the sustained imbalance erodes available operating margins and encroaches on the Transmission Reliability Margin (TRM), resulting in degraded frequency control performance.
- Given the limited TRM – a total of 65 MW to account for all load variability – a large load with frequently changing consumption exploits the available TRM, making it unavailable for other sources of variability and jeopardizing the grid's supply-balance performance.
- Such conditions significantly increase the risk of unintended intertie flow excursions, intertie tripping, frequency and voltage deviations, and, in extreme cases, cascading outages in violation of ARS.

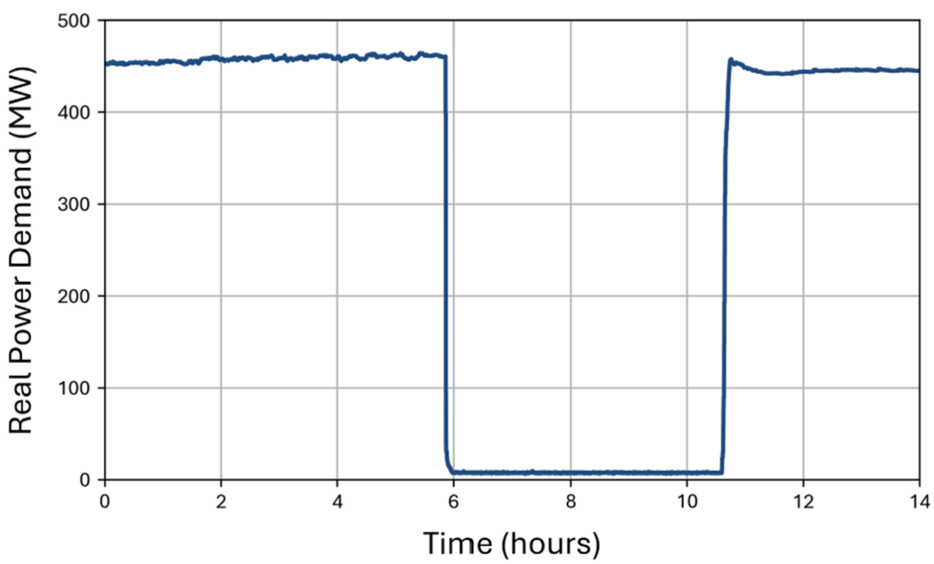

Figure 7-2: A 450 MW Data Centre Facility Load Ramping

Impacts on the AIES

Data centre loads can fluctuate rapidly due to changes in computational demand, cooling requirements or price sensitivity.

- These high and steep ramp rates differ significantly from conventional loads and can create challenges for system balancing and managing ancillary services.
- Ramping behaviour may also lead to power quality issues. Rapid changes in consumption can affect voltage at the POC and neighbouring substations.

- If existing dynamic voltage support devices, such as SVCs and STATCOMs, are insufficient to maintain voltage within the limits outlined in ISO Rule 501.11, additional voltage support may be required.
- Steep ramp events can introduce stability risks. In some cases, data centres can ramp up or down up to levels which potentially leading to system instability or tripping of interties.

The level of risk posed to the AIES depends on the type and operational behaviour of the data centre.

- For example, cryptocurrency mining facilities, which are highly price-sensitive, tend to exhibit more frequent and abrupt ramping compared to cloud data centres that prioritize uptime and stability.

Similar issues are also identified in other jurisdictions. NERC recommends proactive measures such as securing highly responsive resources, improving coordination with data centres, and implementing ramping obligations to maintain compliance with balancing requirements such as Control Performance Standard 1 (CPS1) and Balancing Authority ACE Limit (BAAL)[32] and protect system stability[33].

Current System Capabilities

There are currently limited mechanisms for managing ramp up/down events in AIES:

- Power-Ramp Management Tool
  - Per ISO Rule Section 304.3 (Wind and Solar Power Ramp Up Management), the wind and solar generating facilities with gross real power capability greater than or equal to 5 MWs must be able to limit the rate of increase in real power output (ramp-up) to avoid sudden surges; however, there is no such mechanism for loads.
- Load and Renewable Forecast
  - The AESO's load and renewable generation forecasts provide advance notice to the system controllers to be prepared for the ramp events. However, due to non-conforming nature of TCDC, the forecast cannot provide sufficient information of the TCDC load variability
- Regulating Reserve (RR) and TRM
  - RR and TRM provide short-term balancing capability and reliability margin when other operational tools are insufficient to fully manage ramping events.
  - TRM is not designed to accommodate frequently uncoordinated and/or significantly large load ramps, and the repeated reliance on TRM can erode system flexibility and reliability margins.
  - Based on the historical and current regulating reserve and TRM volume, 10 MW/minute is the maximum ramp up/down that can be accommodated.

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[32] ARS BAL-001-AB-2 Real Power Balancing Control Performance.

[33] NERC, Reliability Guideline, Risk Mitigation for Emerging Large Loads. Atlanta, GA, USA: NERC, May 2025 (Draft).

Requirements

1. Recognizing data centre facilities may not have controls to ramp on a MW/min basis, absent sufficient active mitigations at the POC, coordination of ramp between the facility and AESO real time operations will be required.
2. The TCDC may be required to operate their facility such that its load ramping limit does not go beyond a maximum rate of 10 MW/minute; this applies during ramp-up and down under normal operations and planned outages. All ramp rate measurements are made at the POC with Phasor Measurement Unit (PMU).

Potential Mitigations

Facility solutions:

- The AESO understands there are several technical solutions available to help facilities manage their ramp to comply with the proposed 10MW/min requirement.
  - For example, BTF generation including battery storage and other technologies can be used to manage and comply with ramp rate limits.

7.3 Operational Procedures

Operational procedures are formal, standardized, step-by-step instructions developed by the TCDC facility owner to ensure the necessary communication protocols between the TCDC and the AESO are specified. These procedures include but not limited to:

- Define how the facility transitions between operating states, including:
  - Moving from offline or minimum-load conditions to normal operation.
  - Reducing load in response to system reliability needs or TCDC facility-specific contingencies.
- Ensure compliance with technical requirements.
- Prevent operational or balancing concerns.

Impacts on the AIES

As TCDCs are new to the AIES, the AESO has no historical operational data to rely on when assessing their behaviour under normal and contingency conditions. TCDC designs and applications are not yet well-characterized and can vary widely due to:

- Internal control systems
- Load dynamics
- Computational variability
- Response to system events

These uncertainties amplify operational risk and underscore why clearly defined operational procedures are essential. Without these procedures and clarity of communication protocols:

- The AESO cannot reliably anticipate how a TCDC will behave during ramping, reconnection, or unplanned disturbances.
- System balancing, ACE performance and overall grid reliability may be affected.

Requirements

1. TCDC facility owners may be required to create detailed operational procedures for the AESO to review.
2. Procedures will be required to demonstrate the TCDC can safely reduce its load in preparation of next contingency based on system operating limits (SOL)[34] with controlled load ramp down capability or at discrete blocks which does not pose operations and balancing concerns where the controlled load ramp down capability is infeasible.
3. Planned maintenance activities may need to be scheduled at least six months in advance.
4. Operational procedures will be required to describe the ramp-up characteristics from offline, disconnected, or minimum-load conditions to full load or normal operation, and the ramp-down characteristic from full load to offline or minimum-load conditions. Procedures should define:
   - The threshold below which the electronic load is considered operationally equivalent to “offline”.
   - The threshold above which the electronic load is considered to be operating under normal loading conditions, recognizing that fluctuations around this normal loading condition are inherent to computational processes.
5. Operational procedures should:
   - Specify when the TCDC will notify the AESO control room prior to initiating ramp-up or ramp-down activities (i.e., transitioning from offline or minimum-load conditions to normal operation and vice versa).
   - Include the requirement to provide the AESO with a ramping plan identifying:
     - expected timing;
     - ramp rates;
     - procedural steps; and
     - load-transition stages associated with both ramp-up and ramp-down.

[34] SOLs are the thermal, voltage, stability, and other reliability limits at a TCDC’s point of connection, established through AESO connection and operational studies. Accordingly, the requirement for the TCDC to reduce load in accordance with the SOL means that the operational procedures must ensure the load-reduction actions do not violate any applicable SOLs.

7.4 Reconnection

When breakers at a TCDC are opened for maintenance or trip due to a power disturbance, electrically reconnecting the disconnected portion of the facility can result in a sudden large and rapid load pickup.

Impact on the AIES

- Reclosing a breaker supplying a large load results in a sudden load pickup.
- If the pickup is large and uncoordinated, it can introduce a significant load-generation imbalance, causing frequency excursions during system recovery.
- The near-simultaneous reconnection of multiple large data centres can exacerbate voltage stability issues and materially increase the risk of voltage collapse, particularly in weak or stressed network conditions.

Requirements

1. Once the breaker(s) of the TCDC has been disconnected (opened or tripped) from the transmission system, the operator of the TCDC will be required to request and receive approval from the AESO before electrically reconnecting to the transmission system.
   - This approval is needed for closing any breaker that can lead to net load change more than 50 MW.
2. Installation of automatic reconnection systems will require prior authorization from the AESO.
   - Approved auto-reclose single pole trip and reclose schemes on transmission lines are excluded from this requirement.

Potential Mitigations

To minimise downtime, facilities can:

- Implement pre-approved reconnection protocols
- Engage AESO System Controllers promptly to accelerate restoration.
  - These protocols should outline expected behaviour during reconnection and ramp-up to normal load levels.
- Establish real-time coordination platforms – such as integrated system dashboards and ramp-up management tools – between the AESO and TCDC operators to further enhance reliability and reduce operational risks.

7.5 Real-Time Coordination

The lack of coordination between the AESO and large load operators creates multiple risks, including uncoordinated load ramping and load reconnection. These risks become more pronounced as larger TCDCs are integrated into the system.

Impacts on the AIES

- Without coordinated ramping and reconnection protocols, sudden changes in consumption can strain system balancing and ancillary services.
  - This risk is increased because data centre power consumption is difficult to predict and there is limited historical data.
- Poor forecasts can make it harder to maintain enough supply and can lead to reliability concerns, especially as larger data centres are integrated into the grid.
  - This risk is also highlighted in the NERC Large Load Task Force[35], which recommends implementing real-time coordination processes similar to those used for generators, along with enhanced operator training and communication protocols.

Current System Capabilities

Due to the non-conforming nature of the data centres, AESO system controllers have limited visibility of the load behaviour without communication protocols with the data centre operators.

Requirements

TCDCs will be required to establish some or all the following coordination measures with AESO:

Operational Contacts

1. Designate a primary and backup 24/7 operational point of contact.
2. Each will be required to be trained, authorized, and capable of:
   - Continuous system monitoring and supervisory control
   - Maintaining continuous communication with AESO
   - Responding promptly to AESO instructions

Communication Requirements

3. Primary voice communication:
   - Direct access telephone on the public network
   - Will not be degraded by other functions or data transfers
4. Backup voice communication (for loads ≥ 500 MW):
   - Utility order wire service, satellite telephone, or direct access telephone

Operational Planning

5. Submit an operational plan including hourly average net load at the PCC for the next 14 days and daily demand from 14 days to two years.

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[35] NERC, Reliability Guideline, Risk Mitigation for Emerging Large Loads. Atlanta, GA, USA: NERC, May 2025 (Draft).

6. Data may be used in supply adequacy assessments and forecasts.

Operational Procedures

7. The TCDC facility owner will be required to create detailed operational procedures for the AESO to review that demonstrate the TCDC can safely reduce the power consumption to the MSDC limit on one transmission line with controlled load ramp down capability (also refer to Section 7.2 Ramping).
   - The detailed operational procedures will need to be verified by completing commissioning tests to confirm the ramp down capability of the TCDC.
8. Operational procedures will be required to be contained within the TCDC.
   - Procedures or design which involve the remedial action scheme of generators are not acceptable.

8. Connection Studies

Connection studies assess how the TCDC interacts with the AIES at its specific point of connection. These studies evaluate:

- Potential thermal and voltage criteria violations;
- Short-circuit levels;
- Stability margins; and
- Restoration impacts using system-wide models

Connection studies also determine project-specific obligations – such as reactive power support or advanced controls – that cannot be predefined in requirements alone and must be tailored to local grid conditions.

Through these studies, the AESO can:

- Confirm whether integrating the project will not cause reliability criteria violations.
- Identify any required upgrades or mitigations needed to preserve the safe, reliable operation of the transmission system.

8.1 Connection Study Requirements

Project Modelling

Phasor Domain Modelling

- 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 constant power consumption regardless of voltage variations.

  - If non-VFD-driven machines greater than or equal to five 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.
- TCDCs are represented by a WECC-approved model that captures multiple load components, including:
  - Static ZIP loads
  - Motor loads
  - Electronic loads
- This combined model provides a more accurate representation of the TCDC for stability studies by reflecting a combination of load components, each with distinct electrical and dynamic characteristics, to provide a realistic load representation that aligns with the NERC Load Composition Guideline[36].

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

- **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 participates in a load-shedding program, it must provide a load-shedding model. Currently, LDSHBL is approved by WECC for this purpose.

When NERC or WECC approves a more accurate dynamic model for data centres (e.g., PERC1):

- Its adoption will be required to ensure reliable system studies that reflect actual data centre behaviour.
- The AESO will inform stakeholders on the availability of the new model and new compliance requirements.
- The facility owner is expected to submit the updated model within 180 days from the time it becomes available, regardless of the project stage.

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

Once project-specific dynamic model data and OEM equipment settings become available (including UPS, power electronic converters, static switches, and protection functions), the TCDC facility owner must submit a User Defined Model (UDM) to support AESO stability studies. The UDM must include, to the best of the facility owner's knowledge:

- All applicable ride-through settings.
- The facility's dynamic reactive power capability.

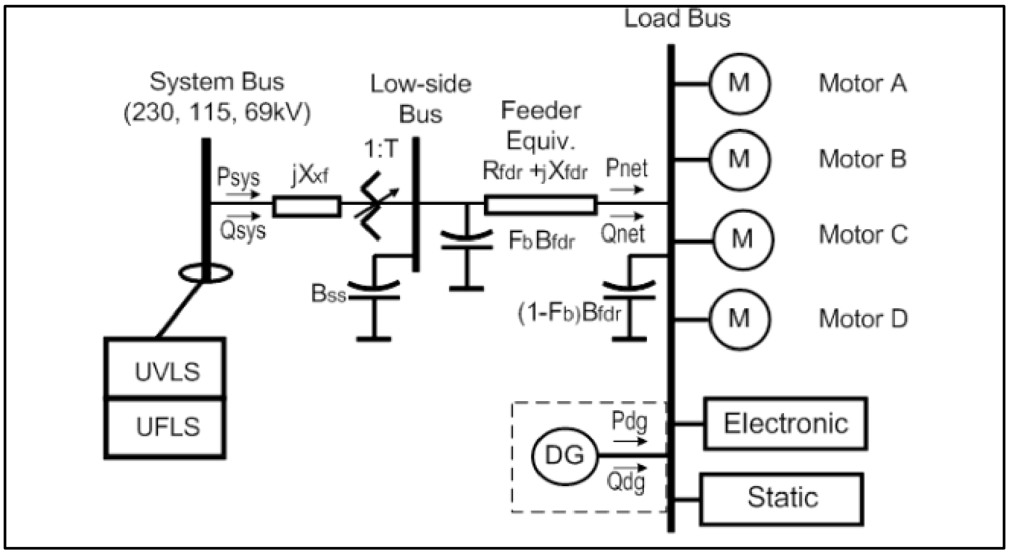


Figure 8-1: CMLD Representation from NERC Load Composition Guideline

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 will need to operate using a one-quarter-cycle timestep.

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 will need to perform baseline testing or otherwise provide evidence based on real-time measurements to confirm the dynamic performance for the following:

- Requirements established in Section 5.3 of this document

- Requirements established in Section 7.1 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 and 4(2) of Section 503.19 of the ISO rules.

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

- Flat Start
- Voltage and frequency step tests
- Voltage and frequency ride-through
- Fault recovery

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

Electromagnetic Transient Modelling

Requirements

1. Submitted EMT models for TCDC will be required to meet the applicable accuracy, usability, and efficiency.
   – Requirements outlined in Information Document Facility Modelling Data and List of Electrical and Physical Parameters for Transmission System Model ID #2010-001R[37] Section A3.3.2.
2. If the TCDC's design includes electric machines used for heating or cooling purposes depending on the Tier class, the model will need to meet the applicable modelling requirements set out in Section A3.3.3.
3. Depending on actual TCDC configuration, the EMT model will need to 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.
   – UPS Systems controls: Detailed representation of control loops (inner and outer), ride-through behaviour (both voltage and frequency), phase locked loop and fault response and limitations.

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

- Static Switches and Bypass Circuitry: Detailed modelling of switching mechanisms and bypass logics.
- Power electronic converters: Representation of AC/DC and DC/DC conversion schemes including controls and protections.
- E-STATCOM and Battery Energy Storage systems, if applicable: Detailed representation of the power electronic circuitry, controls and protection.
- Variable-Speed Drive Systems and electric motors including controls and protections[38].
- Protective Functions or Relays: To represent operational behaviour.
- Plant Control: 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.

4. The EMT model provided for TCDCs will be used in various EMT studies. Therefore, the accuracy and usability of these models will be required to meet the minimum requirements necessary for effective application in the following studies:
   - Ride-through studies
   - Small signal stability (e.g., forced oscillations at sub-synchronous frequencies)
   - Power quality studies (e.g., harmonics, flicker, ramping)
   - Sub-synchronous resonance analysis (e.g., torsional interactions with turbine-generator units)
   - Short circuit and breaker duty studies
   - Effective grounding study
   - Control instability and interactions
5. **Note:** Where aggregation of model components is necessary due to simulation computational limitations, the aggregated representation will be required to reasonably capture and reflect the dynamic response and behaviour of the TCDC, particularly for the intended study objectives.
6. The facility owner will be required to 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.
7. In addition, the facility owner must perform benchmark testing against the Dynamic Phasor Domain model or otherwise provide evidence based on real-time measurements to confirm the performance of the EMT model for the following tests as a minimum:
   - Voltage and frequency ride-through
   - Voltage and frequency step tests
   - System strength

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

- Fault recovery
- Flat start
- Phase angle jump

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

Required Studies

Table 8-1 summarizes the studies that are required at different stages of the connection process for TCDCs. All studies, except system restoration cranking path study, will be done by the MP's consultant while the AESO provides the study scope or guideline on engineering studies.

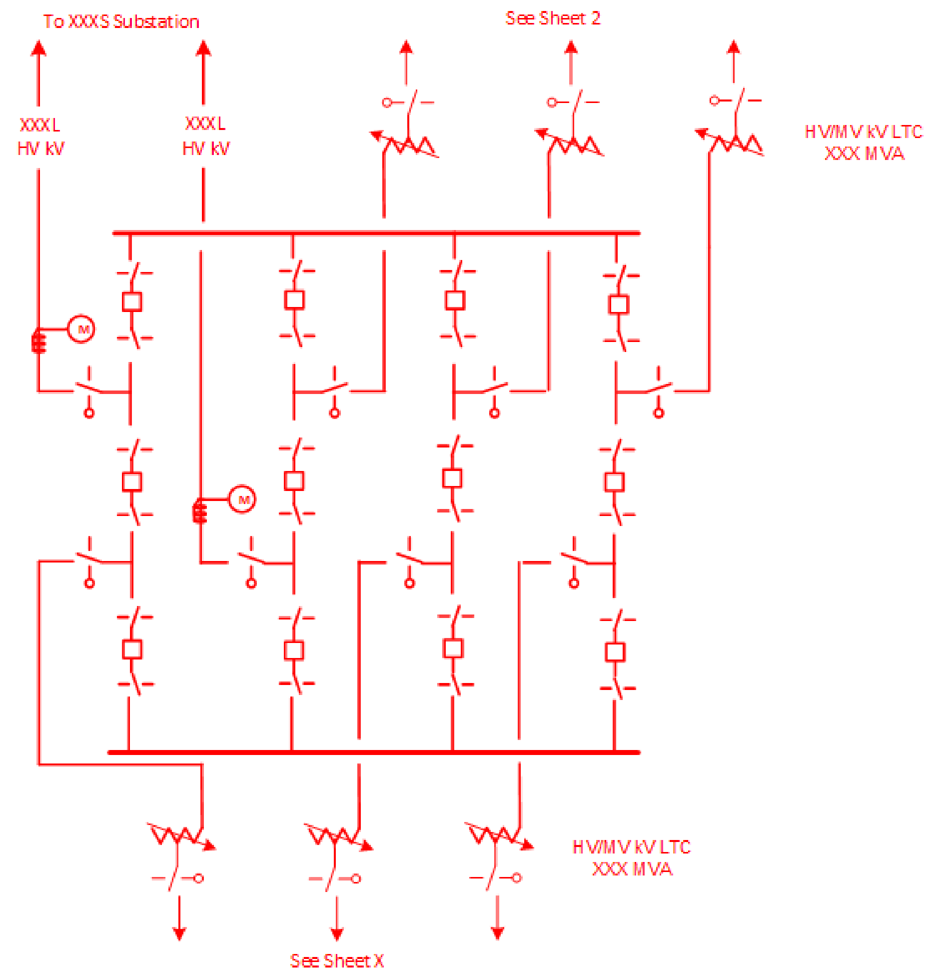
Table 8-1: Summary of Studies Required

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, for Category B, and Selected Category C conditions. Any voltage stability risks require mitigation. These may include additional reactive power support, system upgrade, etc.	2 & 3
Phasor Domain 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 identified. The activation of	3 & 5

	protection schemes, including UFLS 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. Any stability concern during low voltage ride-through must be assessed. 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 maximum and minimum 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 identifies the risk of instability and fault ride through performance issues under low system strength conditions. 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 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	3

	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.	
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 will 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
- Circuit Breaker
- Disconnect Switch
- Motorized Disconnect
- Generator
- Revenue Meter
- Proposed

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.*

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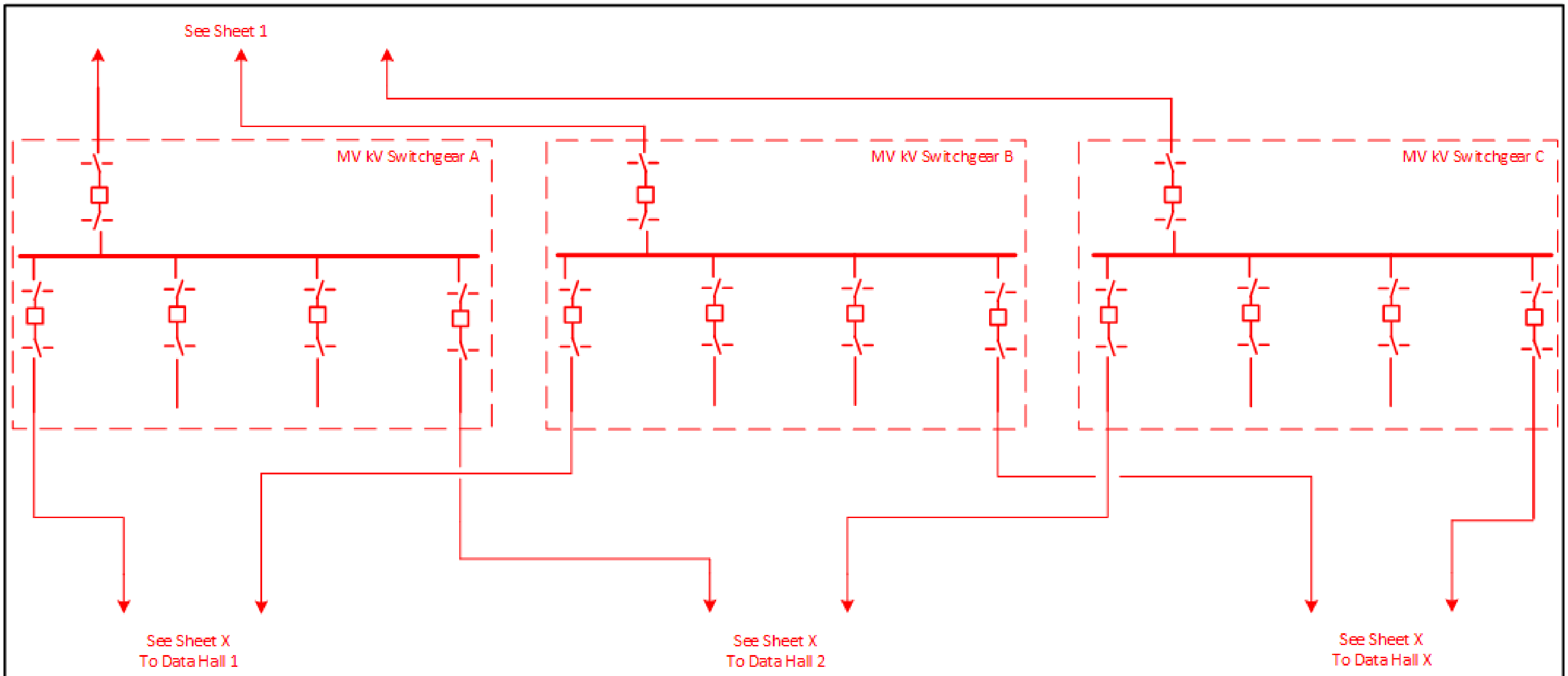
Proposed Data Center Facilities and Connection

PXXXX-XXXS-SLD-1



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Proposed Data Center Facilities and Connection

PXXXX-XXXS-SLD-2

Alberta Electric System Operator

3000, 240 4 Avenue SW
Calgary, AB • T2P 4H4
aeso.ca

06/2026