



California ISO

Large Load Technical Requirements Straw Proposal

Large Load Technical Requirements Working Group

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1. Introduction

The ISO's role with load interconnections being processed by utilities is primarily to ensure that proposed load interconnections are consistent with the ISO's transmission planning and do not create reliability issues on the grid. The ISO coordinates on planning for large loads with local, state, and federal regulators, and is exploring these issues with utility and industry partners in a broader stakeholder initiative. This Large Load Technical Requirements Straw Proposal is one track of a broader set of ISO-led stakeholder discussions around large loads and demand flexibility and is directionally consistent with North American Electric Reliability Corporation (NERC) and industry discussions. The ISO continues to consider large load planning, interconnection, transmission service, operational, and market issues in both the Large Load stakeholder initiative and the Demand and Distributed Energy Market Integration (DDEMI) stakeholder initiative.

The Large Load Technical Requirements Working Group (LLTRWG) was established in October 2025 by the ISO and the utilities interconnecting large data center loads within the ISO footprint, including Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), Southern California (SCE), Valley Energy Authority (VEA), and Silicon Valley Power (SVP). The purpose of the working group is to develop technical requirements for the reliable interconnection and operation of large loads connected to the ISO-controlled grid. This document is focused specifically on technical requirements associated with interconnection and reliable grid operation. It does not establish or address broader planning, market participation, scheduling, or operational requirements applicable within the ISO Balancing Authority Area (BAA), the Extended Day-Ahead Market (EDAM), or the Western Energy Imbalance Market (WEIM), nor does it include forecasting obligations or other market-related requirements. Those aspects are addressed through separate tariff provisions, business practice manuals, and market rules.

As part of this effort, the LLTRWG reviewed technical requirements, operating experience, reliability assessments, and industry guidance developed by other utilities, system operators, and industry organizations, including the NERC, the Energy Systems Integration Group (ESIG), the Electric Power Research Institute (EPRI), and others. In addition, the working group performed parametric dynamic studies on the ISO system to evaluate the potential reliability impacts associated with large loads, including AI-training data centers.

To the extent possible, LLTRWG adopted requirements consistent with existing reliability standards and other entities' requirements. Such consistency helps facilitate a more uniform approach to large load interconnection requirements across different jurisdictions. Specifically, while the ride-through capability requirements are generally aligned with the ride-through requirements specified in NERC PRC-029 for IBRs, they are not intended to exactly replicate the requirements specified in that standard.

Based on these evaluations, LLTRWG developed proposed technical requirements in the following areas:

- Frequency ride-through
- Voltage ride-through
- Post-Fault Active Power Recovery (PFAPR)
- Ramp-rate limitations
- Monitoring and telemetry requirements
- Modeling data requirements
- Commissioning, including data verification and model validation

In parallel, the LLTRWG continues to evaluate additional technical areas that may impact reliable system operation, including:

- Low-frequency cycling limits (to prevent amplification of inter-area oscillations)
- High-frequency cycling limits (to prevent triggering of Subsynchronous Resonance (SSR), Subsynchronous Torsional Interaction (SSTI), and Subsynchronous Control Interaction (SSCI))
- Restrictions on operating in constant-power mode
- Power quality requirements, including harmonics, flicker, and Rapid Voltage Change (RVC)
- Dynamic reactive power support
- Phase-angle jump ride-through capability
- Protection requirements
- Other emerging technical considerations

The LLTRWG recognizes that NERC Project 2026-02 is currently developing reliability standards for computational loads, with completion of phase 1 targeted for the end of 2026. The LLTRWG will continue to monitor the progress of that effort and will work to ensure alignment between the requirements developed through this initiative and applicable NERC reliability standards.

The term “large load” has not yet been formally defined across the industry. The requirements presented in this document are intended to apply to large computational loads, including conventional, AI-training, and crypto mining data centers interconnected to the ISO transmission system.

The requirements presented in this document establish baseline technical expectations for large loads interconnected to the ISO-controlled grid. Depending on project characteristics, electrical location, system strength, concentration of nearby large loads or inverter-based resources (IBRs), and local transmission system conditions including proximity to series-compensated lines, additional or more stringent requirements may be identified through the load interconnection study process.¹

The LLTRWG also recognizes that industry practices, technologies, and reliability standards related to large loads continue to evolve, and the requirements presented in this document may be revised or expanded as additional operating experience, technical studies, and reliability standards become available.

A decision regarding where these requirements will ultimately be documented and enforced—whether through a tariff, ISO Business Practice Manual, utility interconnection handbooks, or another mechanism, as well as whether and to what extent existing customers would be required to comply with these technical requirements, will be made at a later stage.

Each section of this document focuses on a specific technical requirement and generally includes the following subsections:

- **Requirement** – Defines the technical requirement that the large load is expected to meet.
- **Notes** – Provides additional clarification, assumptions, or implementation considerations related to the requirement.
- **Technical Rationale** – Describes the methodology, system studies, engineering considerations, and technical basis used by the LLTRWG in developing the requirement. Where applicable, this section also explains differences between the proposed requirements and those adopted by other entities.
- **Industry Practice** – Summarizes relevant requirements, guidelines, or practices adopted or proposed by other utilities, balancing authorities, reliability organizations, or industry groups. The information provided is not intended to be exhaustive, and industry requirements are continuously evolving. The referenced requirements reflect the information available to LLTRWG at the time this document was prepared.

¹ The current assignment of responsibilities for the system under the ISO's operating control gives lead responsibilities for generation interconnection and transmission planning to the ISO, and load interconnections to the utilities. Given the utilities' lead role in load interconnections, utility federal and state tariffs and state regulations govern the study, interconnection, rates, and cost recovery for serving new loads.

2. Proposed Technical Requirements

2.1. Frequency Ride-Through

Requirement

The frequency ride-through capability requirements are provided in Table 1.

Table 1: Frequency Ride-through Capability Requirements

Frequency (Hz)	Minimum Ride-through Requirement (sec)
>61.8	May trip
>61.2	299
≤ 61.2 and ≥ 58.8	Continuous operation
<58.8	299
<57.0	May trip

Notes

- Frequency measurements shall be taken at the high side of the main power transformer (MPT).
- Frequency calculations shall be based on measurements obtained over an appropriate time window, typically ranging from 3 to 6 cycles.
- Instantaneous or single-point frequency measurements shall not be used for determining protection or control actions.
- Ride-through does not apply when the load trips in response to an ISO/TO-directed underfrequency load shedding program or RAS action. The UFLS and RAS obligation supersedes.
- The working group is continuing to evaluate appropriate Rate of Change of Frequency (RoCoF)-related ride-through requirements for large loads based on system studies, load characteristics, and industry practices.

Technical Rationale

The frequency ride-through requirements are intended to prevent unnecessary tripping of large loads during credible system disturbances and to support overall Bulk Electric System (BES) reliability. The ISO's annual frequency response studies, along with additional studies performed by the LLTRWG as part of this initiative, indicate that system frequency across the Western Interconnection is generally robust and experiences relatively limited deviations from nominal frequency, even following severe contingency events. For example, the ISO's annual frequency response assessment includes scenarios involving the simultaneous trip of two Palo Verde generating units, which represent among the most significant generation-loss events in the Western Interconnection.

The study results indicate that adopting frequency ride-through requirements generally consistent with NERC PRC-029 is technically appropriate for the ISO system and provides alignment with emerging industry practices across North America.

Industry Practice

- ERCOT, SPP, MISO, and LIPA have adopted or proposed frequency ride-through requirements that are generally similar to those presented in this document.

2.2. Voltage Ride-Through

Requirement

The voltage ride-through capability requirements are provided in Table 2.

Table 2: Voltage Ride-through Capability Requirements

Voltage (per unit)	Minimum Ride-through Requirement (sec)
>1.2	May trip
>1.1	2.0
≤ 1.1 and ≥ 0.9	Continuous operation
<0.9	6.0
<0.7	3.0
<0.5	1.2
<0.25	0.15

Notes

- The voltage base used for per-unit calculations shall be the nominal phase-to-phase or phase-to-ground transmission system voltage, as applicable.
- The applicable voltage for evaluating compliance with Table 2 shall be the maximum or minimum fundamental-frequency root mean square (RMS) voltage, measured phase-to-phase or phase-to-neutral at the high side of the main power transformer (MPT).
- Instantaneous trip settings based on voltage measurements with filtering durations shorter than one cycle (16.6 milliseconds) are not permissible.
- At any given voltage value, the large load shall Ride-through unless the time duration at that voltage has exceeded the specified minimum Ride-through duration. If the voltage is continuously varying over time, it is necessary to add the duration within each band of Tables 2 over any 10 second time period.
- The specified duration in Tables 2 is cumulative over one or more disturbances within any 10 second time period.
- Temporary reductions in active power consumption during and after voltage disturbances could occur due to UPS operation, or transitions to backup generation. The LLTRWG is continuing to evaluate and define acceptable levels of temporary power reduction and current increase while operating within the ride-through zones.
- Ride-through does not apply when the load trips in response to an ISO/TO-directed undervoltage load shedding scheme or RAS action. The UVLS and RAS obligation supersedes.

Technical Rationale

The voltage ride-through requirements are intended to minimize unnecessary disconnection of large loads during transmission disturbances and to support reliable BES performance during and following system faults and disturbances.

The ride-through requirement of 6 seconds for the voltage range $0.7 \leq V < 0.9$ pu is generally consistent with the requirements specified in NERC PRC-029 for IBRs and is based on parametric dynamic studies performed on the ISO system. The study results demonstrated that, due to the dynamic characteristics of the load response in certain areas of the ISO footprint, voltage recovery following certain three-phase faults may take 6 seconds or longer to recover above 0.9 pu under specific operating conditions and contingency scenarios.

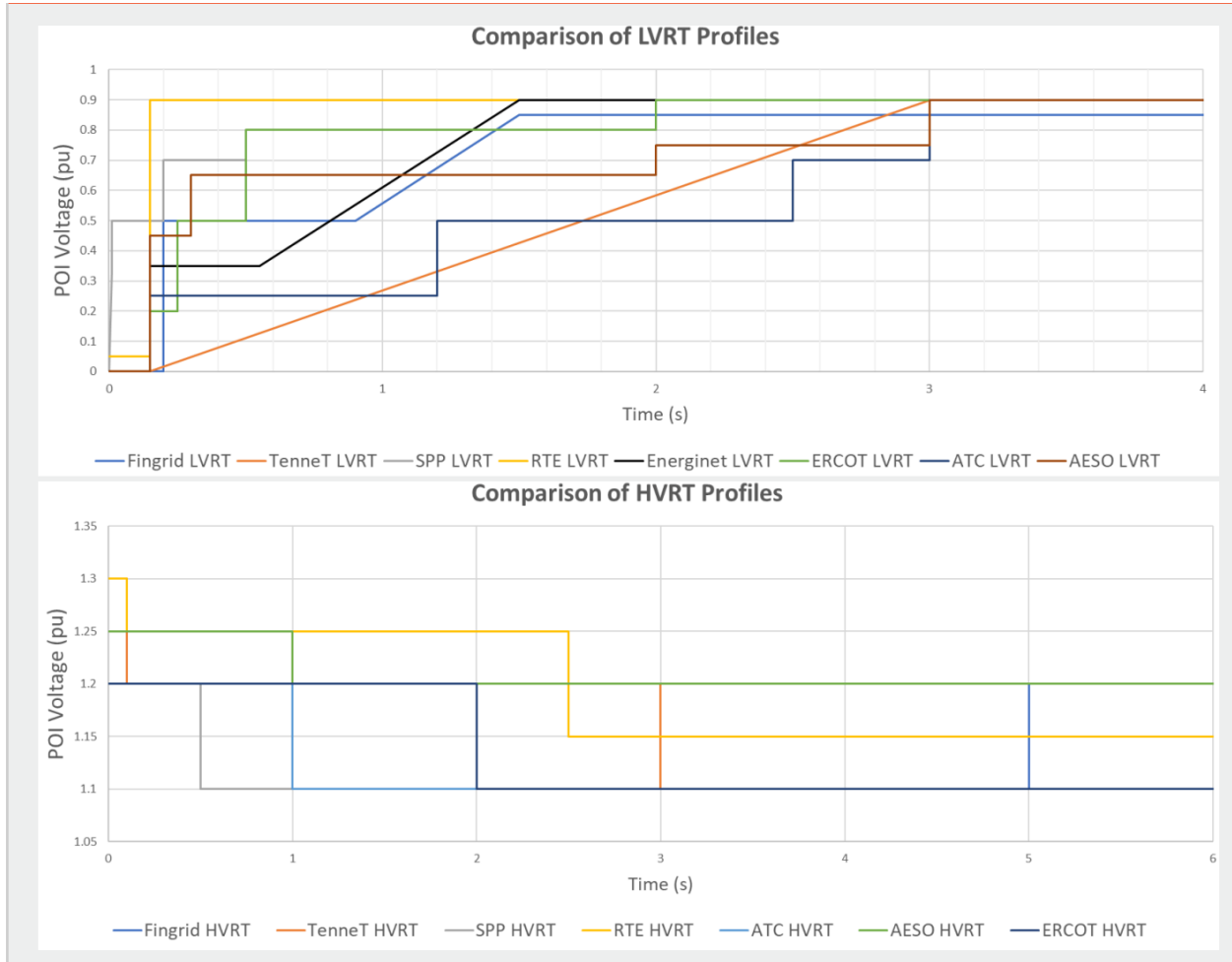
Although some utilities and balancing authorities have adopted shorter ride-through durations for this voltage range, the LLTRWG concluded that adopting a 6-second ride-through requirement is appropriate for the ISO system to avoid unnecessary tripping of large loads during severe but credible system disturbances.

The ride-through requirement of 2 seconds for the overvoltage range $1.1 < V \leq 1.2$ pu is more conservative than the corresponding 1-second requirement specified in PRC-029 for IBRs. This requirement reflects the fact that, under the ISO Planning Standards, steady-state transmission voltages may approach 1.1 pu under certain operating conditions. In addition, dynamic studies performed by the LLTRWG indicated that temporary overvoltage conditions above 1.1 pu may persist for durations exceeding 1 second following major disturbances or switching events. As a result, a 2-second ride-through capability was determined to be appropriate for large loads interconnected to the ISO-controlled grid.

Industry Practice

- Voltage ride-through requirements vary significantly across utilities, balancing authorities, and system operators due to differences in system characteristics, operating practices, and reliability considerations.
- Figure 1 summarizes voltage ride-through requirements adopted or proposed by several entities as of early 2026. These requirements continue to evolve as utilities and reliability organizations gain additional operating experience with large loads.

Figure 1: Low Voltage Ride-Through Requirements
 (Source ESIG Presentation, February 11, 2026)



2.3. Post Fault Active Power Recovery (PFAPR)

Requirement

Large loads shall recover to at least 90% of their pre-disturbance active power level within 3 seconds after the post-fault voltage at the Point of Interconnection (POI) recovers to 0.9 pu or greater.

Notes

- Sustained or repeated reductions in active power after initial recovery are not allowed.
- Additional project-specific requirements may be established where studies identify potential reliability concerns associated with delayed or coordinated load recovery behavior.
- The PFAPR requirement applies to the aggregate active power consumed from the transmission system at the POI.
- If all or part of the large load is required to trip due to RAS action following the fault, the large load will be required to recover to at least 90% of, their pre-disturbance active power level minus the load required to trip due to RAS action, within 3 seconds.
- If all or a portion of the large load is required to trip due to RAS operation following a fault, the required PFAPR level shall be at least 90% of the remaining pre-disturbance load after the RAS-related load reduction, within 3 seconds after the post-fault voltage at the POI recovers to 0.9 pu or greater.

Technical Rationale

To maintain continuity of computational processes during transmission disturbances, many large load facilities, particularly AI-training data centers, incorporate UPS systems and onsite backup generation. These systems are typically designed to maintain uninterrupted service to sensitive computing equipment during voltage disturbances or other grid events.

As part of their control strategy, the facility energy management or site control system may interpret a transient voltage disturbance as a sustained voltage drop and transfer all or a portion of the facility load from the grid to UPS systems or onsite backup generation. While this approach improves the reliability and resiliency of the computational load from the customer perspective, it can create reliability concerns for the BES. From the grid perspective, such actions appear as a sudden and potentially significant loss of load.

The reliability impact becomes more significant when multiple large load facilities are electrically concentrated within the same geographic area or transmission corridor and respond similarly to system disturbances. Simultaneous or coordinated reductions in grid-supplied load following a disturbance can result in undesirable system voltage and frequency response.

The PFAPR requirement is intended to minimize these risks by ensuring that large loads restore their active power consumption following fault clearing and system voltage recovery, within a

defined time. Establishing a minimum active power recovery performance helps maintain predictable system behavior during disturbances and reduces the risk of adverse interactions between large loads and the transmission system.

Industry Practice

- ERCOT: Requires restoration of at least 90% of pre-disturbance active power within 2 seconds.
- AESO: Specifies a default active power recovery time of 1 second, with the capability to adjust the requirement up to 10 seconds depending on system strength and local reliability considerations.

2.4. Ramp Rate Limit

Requirement

The average active power ramp rate of the large load, measured over a rolling 10-minute interval, shall not exceed 20 MW/min.

Notes

- One objective of this requirement is to limit the collective impact of large loads on:
 - Real-time regulation reserve procurement requirements
 - Interconnection frequency variations within the ± 0.036 Hz deadband, beyond which PFR from generators across the Western Interconnection may be triggered.
- Separate requirements may be established to limit faster load variations associated with short-duration cycling, pulsating load behavior, or oscillatory characteristics of the load.
- The ramp-rate requirement applies to normal operating conditions, including routine operational changes and restoration following outages, but does not apply to automatic responses to faults or disturbances required for equipment protection or fault ride-through performance.

Technical Rationale

Each Balancing Authority (BA) is responsible for maintaining its Area Control Error (ACE) below a limit by continuously balancing generation and load within its system. This balancing function is primarily achieved through the procurement and dispatch of regulation reserves capable of responding rapidly to short-term changes in system conditions.

Large loads, particularly AI-training data centers, can exhibit substantial variations in power consumption over relatively short timeframes. Without appropriate ramp-rate limitations, the aggregate behavior of these loads could significantly increase the amount of regulation reserve capacity required to maintain reliable system operation. Such impacts could exceed the regulation requirements traditionally associated with managing variability from conventional load behavior and intermittent generation resources.

In addition, rapid changes in load directly affect Interconnection frequency. Gradual changes can typically be managed through normal regulation service response; however, sufficiently rapid load changes may exceed the response capability of regulation reserves and frequently trigger PFR from generators throughout the Western Interconnection. Frequent activation of PFR can increase mechanical wear on generating equipment and reduce operational flexibility.

The proposed ramp-rate limitation is therefore intended to reduce unnecessary triggering of PFR, limit excessive regulation reserve requirements, and support predictable system operation during normal load variations. The requirement applies to day-to-day operation of large loads, including ramping associated with startup, shutdown, restoration following outages.

The LLTRWG also recognizes that certain large loads may exhibit significant power fluctuations over shorter timeframes, including second-to-second variations and oscillatory behavior. As a result, industry practice is evolving toward establishing additional requirements addressing short-duration load cycling and high-frequency power variations to ensure reliable operation of the BES.

Industry Practice

- ERCOT: 20 MW/min
- ATC: Any active power change greater than 50 MW must be limited to a ramp rate of less than 0.5 MW/s (30 MW/min)
- AESO: 10 MW/min
- Southern Company: 20 MW/min. In addition, the top quartile (P75) of active power ramp rate, as averaged across consecutive 1-minute periods, should also not exceed 20 MW/min.

2.5. Monitoring and Telemetry

Requirement

High-resolution monitoring and telemetry equipment, including Phasor Measurement Units (PMUs), Digital Fault Recorders (DFRs), and SCADA systems shall be installed at each Main Power Transformer (MPT) associated with the large load interconnection.

Notes

- Interconnection studies may identify the need for additional monitoring capabilities depending on reliability risks.
- PMU and SCADA measurements shall be streamed in real time to the interconnecting Transmission Owner (TO).
- DFR measurements shall be retained for a minimum of 30 days and provided to the TO upon request within 10 days.
- Depending on the results of the interconnection studies, the interconnecting TO may require additional monitoring, control, or protective systems to maintain BES reliability. Such systems may include automated schemes designed to reduce or disconnect portions of the large load during abnormal system conditions.

Technical Rationale

The rapid pace of large load interconnections within the ISO footprint, combined with the limited industry operating experience with such facilities, particularly AI-training data centers, creates a need for enhanced system visibility and high-resolution monitoring capabilities.

Large loads may exhibit fast-changing power consumption characteristics, complex interactions with power electronic equipment, and coordinated responses to transmission disturbances that may contribute to unexpected dynamic performance, oscillatory behavior, or other reliability concerns that may not be fully observable through conventional SCADA measurements alone.

The installation of high-resolution monitoring equipment, including PMUs, and DFRs, provides the ability to capture dynamic system behavior during both normal operation and disturbance conditions. Real-time streaming of monitoring data supports operational awareness, event analysis, oscillation detection, model validation, and identification of abnormal system interactions. These measurements also support post-event engineering analysis and facilitate the development of mitigation measures when reliability concerns are identified.

The LLTRWG believes that enhanced monitoring and telemetry capabilities are important to ensure that any unexpected interactions between large loads and the transmission system can be identified and addressed promptly through automated protection systems, operational actions, or future design improvements.

Industry Practice

- ERCOT: Requires installation of PMUs, Sequence of Events (SOE) recording equipment, and Digital Fault Recorders (DFRs).
- ATC: Requires monitoring of the aggregate large load facility at sufficient resolution and to retain at least 90 days of operational data.
- AESO: Requires installation of PMUs and real-time streaming of specified synchrophasor measurements.
- Southern Company: Requires monitoring equipment, including PMUs, Advanced Digital Fault Recorders (ADFRs), and Continuous Wave Streaming devices, to support wide-area oscillation detection at the Point of Connection unless determined otherwise by Southern Company Transmission.

2.6. Modeling Data

Requirement

Attachment A identifies the modeling and technical data that large load interconnection customers are required to provide to the interconnecting Transmission Owner (TO) to support system impact studies and reliability assessments. Depending on the project characteristics and study phase, the TO may require submission of power flow, dynamic, short-circuit, and/or EMT models and associated technical data.

Notes

- The modeling data requirements are generally aligned with the NERC large load modeling data questionnaire and related industry guidance documents.
- Additional load profile information, control system details, operational characteristics, or model data may be required by the interconnecting TO based on the characteristics of the load, system conditions, or study results.
- The TO may require updated or revised models during different phases of the interconnection process, including planning, commissioning, and post-commercial operation model validation activities.
- Submitted models and technical data shall accurately represent the expected steady-state and dynamic performance of the facility, including any load management systems, UPS systems, onsite generation, or other control systems that may impact system behavior during normal or disturbance conditions.
- Where applicable, EMT models shall include sufficient detail to support evaluation of fast dynamic interactions, converter and UPS behavior, control system performance, harmonic impacts, and other sub-cycle phenomena relevant to system reliability.

Technical Rationale

Accurate modeling data is essential to enable the interconnecting TO and the ISO to perform reliable system impact studies and evaluate the potential effects of large loads on the BES. Depending on the size, location, and operating characteristics of the project, large loads may significantly influence steady-state power flows, system dynamics, voltage performance, frequency response, fault behavior, oscillatory performance, and electromagnetic transient interactions.

The requested modeling information and supporting technical data enable the TO to perform detailed planning, operational, protection, and reliability studies across multiple simulation domains, including power flow, transient stability, short-circuit, and EMT analysis. Accurate models are particularly important for evaluating facilities with rapidly varying load behavior, complex power electronic equipment, UPS systems, onsite generation, or advanced control systems.

In addition, validated and up-to-date models support ongoing planning assessments, operational studies, disturbance analysis, and future reliability evaluations as system conditions evolve over time.

Industry Practice

Other entities have established similar load modeling and technical data submission requirements for large load interconnections.

2.7. Commissioning

Requirement

Large load interconnection customers shall provide written commissioning and testing procedures to the interconnecting Transmission Owner (TO) prior to energization and commercial operation for TO's review and approval. The commissioning process shall include verification of load characteristics, validation of applicable models, and demonstration of compliance with the technical requirements specified in this document.

Notes

At a minimum, the commissioning and testing process shall include the following:

- Validation of load profiles and operational behavior to demonstrate compliance with applicable ramp-rate and load variability requirements.
- Validation of power flow, dynamic, and, where applicable, EMT models used in the interconnection studies.
- Verification that any protection, control, or remedial action systems designed to reduce or disconnect portions of the large load operate as intended.
- Verification of monitoring and telemetry systems, including PMU, SCADA, DFR, as applicable.
- Submission of commissioning test results, disturbance recordings, and model validation data to the interconnecting TO and ISO upon request.
- Additional commissioning or performance verification requirements may be established based on project-specific reliability considerations identified during the interconnection study process. If the interconnection study identifies stability risk, the commissioning process shall include an EMT model validation exercise using approved simulation tools.
- If certain validations or performance verifications cannot be completed during the initial commissioning phase, the commissioning and testing procedure document shall identify which tests are deferred, the schedule for completing those tests, and the basis for concluding that the deferred testing will not adversely impact system reliability or the validity of the interconnection study assumptions.
- If the large load facility does not satisfy the applicable commissioning or technical requirements, the interconnecting TO may require corrective actions, operational limitations, additional studies, mitigation measures, or re-validation activities prior to or following commercial operation.

Technical Rationale

Large loads may have a significant impact on the reliable operation of the system. As a result, it is important to ensure that the actual operating characteristics of the facility are consistent with the assumptions, models, and performance characteristics used during the interconnection studies.

A coordinated and comprehensive commissioning process provides the opportunity to validate facility performance under actual operating conditions, verify the accuracy of submitted models and load data, and confirm that protection, control, and monitoring systems operate as intended. This process also helps identify potential discrepancies between expected and actual facility behavior before the project enters normal operation.

Validation of load profiles, ramp-rate behavior, disturbance response, telemetry systems, and applicable power system models improves the accuracy of future planning and operational studies and supports reliable system operation following commercial energization.

The commissioning process is also intended to establish sufficient operational visibility to support ongoing monitoring, event analysis, and future model validation activities.

Industry Practice

- Southern Company: The “Integration Process for Transmission-Connected Large Loads” includes detailed commissioning, testing, monitoring, and performance verification requirements for large load interconnections.

3. Technical Requirements Under Development

The LLTRWG continues to evaluate additional technical requirements associated with large loads and their potential impact on reliable operation of the system. The following sections summarize technical areas currently under development.

3.1 Low Frequency Cycling

Requirement

To be determined.

Notes

The objective of this requirement is to prevent amplification of inter-area oscillations, avoid adverse interactions with generator controls and system damping characteristics, and minimize unnecessary activation of balancing and frequency response resources.

The following topics are being considered for this requirement:

- Magnitude and duration of low-frequency active power variations
- Frequency-domain characteristics of load oscillations
- Aggregate behavior of geographically concentrated large loads
- Potential interactions with weak-grid conditions, IBRs, and existing system oscillatory modes.

Technical Rationale

Large loads, particularly AI-training data centers, may exhibit periodic or oscillatory active power behavior over timeframes ranging from several seconds to multiple minutes. If not properly managed, coordinated or sustained low-frequency load cycling could interact with existing electromechanical oscillation modes within the transmission system and potentially reduce system damping or amplify inter-area oscillations.

Traditional load models and operating practices have historically assumed relatively smooth aggregate load behavior. Additional technical requirements may be necessary to ensure that large loads do not introduce undesirable oscillatory characteristics into the power system.

Industry Practice

- ATC and SPP: Require active power variations to remain below 25 MW over a 5-second interval.
- Southern Company: Requires active power variations to remain below 10 MW over a 4–6 second interval.

- ERCOT: Have proposed limiting active power variations to less than 10 MW over a 5-second interval.
- LIPA: Requires frequency-domain content in the 0.1–5 Hz range to remain below 10 MW and content in the 5–55 Hz range to remain below 3.5 MW.

3.2 High Frequency Cycling

Requirement

To be determined.

Notes

The objective of this requirement is to prevent adverse interactions between large loads and transmission system, IBRs, synchronous generator shaft systems, and power electronic controls.

The following topics are being considered for this requirement:

- Frequency-domain characteristics of load variations and oscillatory behavior
- Potential excitation of SSR, SSTI, SSCI, or other oscillatory phenomena
- Interactions between large loads and IBRs, FACTS devices, HVDC systems, or series-compensated transmission facilities
- Appropriate Fast Fourier Transform (FFT)-based methodologies, filtering techniques, averaging windows, and performance metrics
- The aggregate impact of geographically concentrated large loads operating with similar control characteristics.

Technical Rationale

Large loads, particularly AI-training data centers and facilities utilizing high-speed power electronic equipment, may exhibit active power fluctuations across a wide range of frequencies. Such variations may interact with existing oscillatory modes of the transmission system or excite resonant conditions that could negatively impact system reliability.

Of particular concern are interactions involving IBRs, series-compensated transmission lines, FACTS, HVDC converter controls, and generator shaft torsional modes. Under certain conditions, repetitive or sustained high-frequency cycling behavior may contribute to adverse dynamic interactions, reduced system damping, equipment stress, or unintended operation of protection and control systems.

The reliability risk associated with high-frequency cycling behavior is expected to be system-dependent and may vary significantly based on system configuration and operating conditions.

Industry Practice

- ATC, SPP, and MISO: Require system impact studies to demonstrate that large loads do not create adverse reliability impacts on the system.

- Southern Company: Requires the frequency-domain content of the load profile, calculated using FFT analysis, to remain below specified limits across multiple frequency bands, including 0.1–0.5 Hz, 0.5–0.8 Hz, 0.8–2 Hz, and 5–55 Hz.
- LIPA: Requires frequency-domain content in the 0.1–5 Hz range to remain below 10 MW and content in the 5–55 Hz range to remain below 3.5 MW.

3.3 Limits on operating in constant power mode

Requirement

To be determined.

Notes

The following topics are being considered for this requirement:

- The dynamic behavior of power electronic load controls during voltage disturbance
- Potential impacts on transmission system voltage recovery and system stability
- Interactions with IBRs and weak-grid conditions
- The aggregate effect of multiple large loads operating with similar control characteristics
- Appropriate operational limitations or control requirements during transient voltage events.

Technical Rationale

Many large loads utilize power electronic interfaces and control systems designed to maintain relatively constant active power consumption over a wide range of operating conditions. During voltage depressions, constant power operation may cause the load to draw increased current from the transmission system to maintain its active power consumption.

Under certain system conditions, this behavior may negatively impact voltage recovery following disturbances, increase reactive power demand, reduce system damping, or contribute to voltage instability. The aggregate response of multiple large loads operating in constant power mode may further amplify these effects.

The potential reliability impacts are expected to depend on several factors, including system strength, load composition, control system design, disturbance severity, and the dynamic interactions between large loads and nearby generation resources.

Industry Practice

- ATC and SPP: Do not permit operation in constant power mode during voltage sag conditions due to concerns regarding adverse impacts on transmission system reliability and voltage recovery performance.

3.4 Power Quality (harmonic, flicker, Rapid Voltage Change, ...)

Requirement

To be determined.

Notes

The following topics are being considered for this requirement:

- Harmonic current and voltage distortion
- Voltage flicker and Rapid Voltage Change (RVC)
- Subharmonic and interharmonic emissions
- Power quality impacts associated with rapidly varying loads
- Continuous power quality monitoring and reporting requirements
- Potential cumulative impacts resulting from geographically concentrated large loads.

The LLTRWG is also evaluating appropriate measurement methodologies, compliance criteria, monitoring requirements, and applicable industry standards for power quality performance.

Technical Rationale

Large loads, particularly AI-training data centers, may contribute to harmonic distortion, flicker, rapid voltage fluctuations, interharmonics, and other waveform abnormalities that may adversely affect transmission equipment, customer loads, IBRs, and overall system reliability.

The potential impact of power quality disturbances depends on several factors, including facility size, load composition, converter technologies, local system strength, network impedance characteristics, and the aggregate behavior of nearby large loads and IBRs.

As the penetration of large loads increases, the cumulative impact of harmonics and rapidly varying load behavior may become more significant, particularly in electrically weak areas of the system. Continuous monitoring and appropriate technical limits may therefore be necessary to ensure acceptable system performance and compliance with applicable reliability and power quality standards.

Industry Practice

- ATC, Dominion, AEP, and AESO: Require compliance with IEEE 519-2022 harmonic limits at the Point of Common Coupling (PCC), IEEE 1453 flicker and Rapid Voltage Change (RVC) limits, and continuous power quality monitoring at the POI.
- ERCOT and SPP: Are expected to propose similar power quality requirements for large loads.

3.5 Power Factor and Dynamic reactive support

Requirement

To be determined.

Notes

The following topics are being considered for this requirement:

- Steady-state power factor requirements at the POI
- Dynamic reactive power performance during normal and system disturbance conditions
- Voltage support capabilities during transmission contingencies and voltage disturbance events
- Coordination with IBRs and nearby reactive support devices
- Reactive power impacts associated with rapidly varying loads
- The aggregate impact of geographically concentrated large loads on local and system-wide voltage performance.

Technical Rationale

Large loads may have a significant impact on transmission system voltage performance and reactive power requirements. Depending on their operating characteristics, large loads may contribute to increased reactive power demand, voltage fluctuations, reduced voltage stability margins, and degraded post-disturbance voltage recovery performance.

Many large loads utilize power electronic equipment, UPS systems, and advanced control systems that may dynamically influence reactive power consumption and voltage behavior during both normal operation and system disturbances. As the penetration of these facilities increases, maintaining acceptable voltage performance and reactive power balance across the transmission system may require additional technical requirements related to steady-state power factor operation and dynamic reactive support capabilities.

Industry Practice

- Based on section 8.2.3.3 (Voltage Support) of the ISO Tariff:
“... All Loads directly connected to the CAISO Controlled Grid shall maintain reactive flow at grid interface points within a specified power factor band of 0.97 lag to 0.99 lead. Loads shall not be compensated for the service of maintaining the power factor at required levels within the bandwidth. A UDC interconnecting with the CAISO Controlled Grid at any point other than a Scheduling Point shall be subject to the same power factor requirement...”

- SPP, ATC, LIPA, and AESO: Require operation within a ± 0.95 power factor range at the POI.
- MISO: Has proposed a ± 0.95 power factor requirement at the POI.
- Southern Company: Requires operation within a ± 0.90 power factor range at the POI.

3.6 Phase Angle Jump Ride Through

Requirement

To be determined.

Notes

The following topics are being considered for this requirement:

- The ability of large loads to remain connected during transient phase angle shifts resulting from system disturbances, switching events, or fault clearing
- Potential interactions between load control systems, UPS systems, IBRs, and protection systems during phase angle disturbances
- Appropriate ride-through limits, measurement methodologies, and performance criteria
- The aggregate impact of load responses to phase angle disturbances in electrically weak areas or regions with high concentrations of large loads.
- Utilizing IEEE-2800 requirement on phase angle jump ride-through as a reference.

Technical Rationale

Transmission system disturbances, fault clearing events, switching operations, and network reconfigurations may result in temporary phase angle shifts across the transmission system. Depending on the magnitude and rate of the phase angle change, sensitive load control systems, UPS equipment, synchronization controls, or protection systems may respond by reducing load, transferring to backup systems, or disconnecting from the grid.

Large loads may be particularly sensitive to such disturbances. Coordinated or widespread responses to phase angle jumps could potentially result in sudden changes in active or reactive power consumption, undesirable dynamic interactions, or reduced system stability margins.

Industry Practice

Industry practices and technical requirements related to phase angle jump ride-through for large loads are currently evolving. The LLTRWG continues to monitor industry developments, utility requirements, and emerging reliability standards in this area.

3.7 Protection Requirements

Requirement

To be determined.

Notes

The following topics are being considered for this requirement:

- Protection system coordination between large loads and the transmission system
- Voltage, frequency, and Rate of Change of Frequency (RoCoF)-based protection settings
- Coordination of load protection systems with ride-through requirements and system reliability objectives
- Protection system behavior during transmission faults, switching events, oscillatory conditions, and abnormal system conditions
- The use of remedial action schemes, load-shedding schemes, or special protection systems to maintain system reliability
- The aggregate impact of coordinated or simultaneous operation of protection systems associated with multiple large loads.
- For any customer back up generation including UPS that will only operate when the large load is isolated from the interconnecting TO System (e.g., in island-mode), the large load will be required to install interlocks acceptable to the TO to prevent the customer-owned generation from coming on-line or generating when the large load is synchronized to the TO system.

Technical Rationale

Protection systems associated with large loads can significantly influence transmission system performance during disturbances and abnormal operating conditions. Improperly coordinated or overly sensitive protection settings may result in unnecessary or widespread disconnection of large loads following transmission faults, voltage depressions, frequency excursions, oscillatory events, or other system disturbances.

Because large loads may represent concentrated demand as an aggregate, simultaneous or coordinated tripping of these facilities could result in sudden load loss, excessive frequency and voltage excursions, and other adverse impacts on reliability.

In addition, many large loads utilize advanced control architectures that may introduce complex interactions between facility-level protection systems and transmission system dynamics. Protection system coordination is therefore important to ensure that the facility appropriately

distinguishes between disturbances that require equipment protection and those for which continued ride-through operation is necessary to support reliable system performance.

Industry Practice

Industry practices and technical requirements related to protection systems for large loads continue to evolve. Utilities, balancing authorities, and reliability organizations are actively evaluating appropriate protection coordination requirements, ride-through expectations, and remedial action approaches for large load interconnections.

3.8 Other Emerging Technical Requirements

Requirement

To be determined.

Notes

Potential future areas of evaluation may include, but are not limited to:

- Emerging dynamic performance characteristics associated with large loads
- Interactions between large loads and IBRs, HVDC systems, FACTS devices, and advanced transmission technologies
- Advanced monitoring, telemetry, and real-time performance assessment requirements
- Cybersecurity and operational coordination considerations associated with large load facilities
- Aggregated impacts of geographically concentrated large loads on system reliability and operational flexibility
- Additional reliability requirements identified through NERC standards and guideline development activities, disturbance investigations, or industry operating experience.
- Coordinated or simultaneous loss of large loads across multiple facilities resulting from common-mode IT, communication network, cloud-service, control system, or cybersecurity events, rather than transmission system disturbances, may present unique reliability risks to the BES. The LLTRWG may evaluate whether additional operational, coordination, monitoring, or performance requirements are necessary to address such scenarios.
- The interconnecting TO may require updated studies, revised modeling data, or additional operational coordination requirements when significant changes occur to facility configuration, operating characteristics, control systems, or load behavior following commercial operation.

Technical Rationale

As industry practices, technologies, and system conditions continue to evolve, new reliability considerations may emerge that are not fully addressed by existing planning criteria, operating practices, or technical requirements.

The large scale, rapid growth, and increasingly dynamic behavior of these facilities may create new operational and planning challenges for the grid.

Given the evolving nature of these technologies and the limited long-term operating experience currently available, the LLTRWG believes it is important to maintain flexibility to develop additional technical requirements as necessary to support reliable system operation.

Industry Practice

Many entities are actively evaluating additional reliability requirements beyond those currently established, particularly in areas related to dynamic performance, oscillatory behavior, power quality, monitoring, protection coordination, and advanced control system interactions.

4. References

- [1] NERC Level 3 Computational Load Alert – *Essential Action to Industry; Computational Load Modeling, Studies, Instrumentation, Commissioning, Operations, Protection, and Control, May 2026*
<https://www.nerc.com/globalassets/programs/bpsa/alerts/level-3-computational-load-alert.pdf>
- [2] NERC Level 2 Large Load Alert – *Industry Recommendation; Large Load Interconnection, Study, Commissioning, and Operations, September 2025*
<https://www.nerc.com/globalassets/programs/bpsa/alerts/2025/nerc-alert-level-2--large-loads.pdf>
- [3] NERC Reliability Guideline – *Large Loads Reliability Impacts and Recommended Modeling Practices, May 2026*
https://www.nerc.com/globalassets/who-we-are/standing-committees/rstc/draft_reliabilityguideline_riskmitigationforemerginglargeloads.pdf
- [4] NERC Project 2026-02 – *Computational Load Reliability Standards Development*
<https://www.nerc.com/standards/reliability-standards-under-development/2026-02-computational-loads>
- [5] NERC White Paper – *Assessment of Gaps in Existing Practices, Requirements, and Reliability Standards for Emerging Large Loads, March 2026*
<https://www.nerc.com/globalassets/our-work/guidelines/reliability/white-paper---assessment-of-gaps.pdf>
- [6] NERC – *Large Load Modeling Data Questionnaire, March 2026*
<https://www.nerc.com/globalassets/who-we-are/standing-committees/rstc/lmwg/data-center-information-collection-questionnaire.pdf>
- [7] NERC – Large Load Working Group
<https://www.nerc.com/who-we-are/committees/reliability-and-security-technical-committee-rstc/subcommittees-working-groups-and-task-forces/large-loads-working-group-llwg>
- [8] ESIG – Large Load Working Group
<https://www.esig.energy/working-groups/large-loads/>
- [9] ERCOT – Large Load Working Group
<https://www.ercot.com/committees/tac/llwg>
- [10] Southern Company – *Technical Requirements for Transmission Connected Large Loads, effective May 1st, 2026*
https://www.oasis.oati.com/woa/docs/SOCO/SOCodocs/SOCO_Technical_Requirements_for_TCLLs_-_v1.4_2026-05-01.pdf
- [11] American Transmission Company (ATC) – *Transmission System Planning Criteria*
https://cdn.misoenergy.org/ATC_TO_Planning_Criteria108210.pdf
- [12] NERC Reliability Standards PRC-024-04 – *Frequency and Voltage Protection Settings for Synchronous Generators, Type 1 and Type 2 Wind Resources, and Synchronous*

Condensers

<https://www.nerc.com/globalassets/standards/reliability-standards/prc/prc-024-4.pdf>

- [13] NERC Reliability Standards PRC-029-1 – *Frequency and Voltage Ride-through Requirements for Inverter-based Resources*

<https://www.nerc.com/globalassets/standards/approved-standards/prc/prc-029-1.pdf>

- [14] California ISO Planning Standards, *Effective February 2nd, 2023*

<https://www.caiso.com/documents/iso-planning-standards-effective-feb22023.pdf>

- [15] Alberta Electric System Operator (AESO) – Connection Requirements for Transmission Connected Data Centers – *Draft for Stakeholder Review, August 22nd, 2025* ([Link](#))

- [16] Long Island Power Authority (LIPA) – *Performance Requirements for Large Loads Connected to the LIPA System – February 18, 2026*

<file:///T:/ERahimi/PerformanceRequirementsLargeLoadsConnectedLIPASystem.pdf>

5. Acronym Definitions

Acronym	Definition
ACE	Area Control Error
ADFR	Advanced Digital Fault Recorder
BA	Balancing Authority
BES	Bulk Electric System
CAISO	California Independent System Operator
DFR	Dynamic Fault Recorder
EMT	Electromagnetic Transient
ESIG	Energy Systems Integration Group
FACTS	Flexible AC Transmission Systems
FFT	Fast Fourier Transform
HVDC	High-Voltage Direct Current
IBR	Inverter-Based Resource
LLTRWG	Large Load Technical Requirements Working Group
MPT	Main Power Transformer
PCC	Point of Common Coupling
PFAPR	Post-Fault Active Power Recovery
PFR	Primary Frequency Response
PMU	Phasor Measurement Unit
POI	Point of Interconnection
RMS	Root Mean Square
RoCoF	Rate of Change of Frequency
RVC	Rapid Voltage Change
SCADA	Supervisory Control and Data Acquisition
SOE	Sequence of Events
SSR	Subsynchronous Resonance
SSCI	Subsynchronous Control Interaction
SSTI	Subsynchronous Torsional Interaction
TO	Transmission Owner
UPS	Uninterruptible Power Supply