

Large Load Interconnection Reliability Requirements (LLWG)

Updated on 4/17/2026
- Large Load definition language update on slide 6
- Expanded requirement condition on slide 7
- Updated Ramp Requirement on slide 10

Large Load Working Group

April 20, 2026

Purpose & Key Takeaway



Purpose

Establish clear, consistent requirements for large load interconnection and operation to support system reliability across the MISO footprint

Key Takeaways

- Large, concentrated loads can create significant transmission planning and operational challenges.
- Clear, standardized requirements provide predictable system behavior and support timely, effective reliability planning.
- Early definition of requirements enables meaningful impact assessments, reduces late-stage design changes, and improves overall project outcomes.
- These requirements form the foundation for developing comprehensive, stakeholder-driven interconnection reliability standards.

MISO is working towards three desired outcomes that warrant stakeholder consideration

Interconnection reliability requirements	A set of guidelines and requirements needed to support reliability are defined for large load at the time of interconnection.
Speed to reliable power	Large load can secure service quickly and without compromising reliability, accounting for the unique characteristics and commitments of the facility.
Reliable operations	The grid is operated reliably and efficiently with substantial levels of large load.

Note: Outcomes and specific implementing mechanism may evolve or change during development

MISO's intent is to build on these well-developed industry artifacts while assessing and refining the approaches that best fit an RTO/ISO context

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

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Appendix A: High-Level Recommendations

Category	Recommendation	LLE	DP	TO	TP	PC	TOP	BA	RC
Data Collection and Modeling	Provide steady-state, dynamic, and other data	P	L	L	SR	SR			
	Install high-speed FR, DDR, and SER	L	C	C					
	Provide high-speed recording data for post-event analysis	P	C	C	C	C	SR	SR	SR
	Provide updates to modeling data (as-built)	P	L	L	SR	SR			
	Provide real-time electrical measurements	P		P			SR	SR	SR
	Provide near-term demand forecasts	P		C				SR	SR
	Perform model quality assessment, model verification, model validation	L			SR	SR			
Interconnection	Collect data and share with relevant entities	C	L	L	SR	SR	SR	SR	SR
	Study reliability impacts of new large load	C	C	C	L	L	M	M	M
	Periodic near-term studies for collective impact of new large loads	C	C	C	L	L	M	M	M
	Comprehensive commissioning process for large loads	C	C	C	C	C	SR	SR	SR
	Develop EMT screening criteria where needed	M	C	C	SR	SR			M

C = Coordinate · L = Lead · M = Monitor · P = Provide · SR = Specify Requirements

[NERC Reliability Guideline Risk Mitigation for Emerging Large Loads]

MISO is centering on ramping limits, improved data and modeling, system stability and robust ride-through performance

Ramp and Repetitive Changes in Load Active Power Requirements	Ensure large loads do not introduce sudden step changes that challenge system balancing, voltage control, or contingency response.
Data, Modeling, and Telemetry Requirements	Provide basic facility data, modeling, real-time telemetry, short-term forecasting, outage and other data needed for accurate representation of load behavior and system impacts.
Ride-Through Requirements	Prevent large load unexpected disconnection during disturbances by establishing clear minimum expectations for ride-through and post-disturbance recovery.
Stability Assessment Requirements	Establish standardized procedures to evaluate the impact of large loads on system stability, including voltage, frequency, and dynamic interactions, accounting for fast-changing behavior, high reactive demand, and performance under weak grid conditions.

The draft Large Load definition (PAC-2024-1) has been revised based on stakeholder feedback and will be further discussed at the PAC on April 22 before finalizing

- **Large Load** - The load associated with any commercial or industrial facility or aggregation of such facilities that is owned, operated, or controlled by a single entity or group of entities that will coordinate with respect to the load profile of the large load, connected to the Transmission System, and that:

  (1) results for the first time after September 1, 2026, in a total load that exceeds 50 MW of total capacity at a single site behind one or more ~~P~~points of ~~I~~interconnection to the Transmission System as further described in the Business Practice Manuals ; or

  (2) for load that already exceeds 50 MW of total capacity as of September 1, 2026, any new facilities or expansion that collectively increase the capacity of the load by 25 MW or more interconnection ~~at a single site behind one or more Points of Interconnection~~ above the value documented as of September 1, 2026, at a single site behind one or more points of interconnection to the Transmission System as further described in the Business Practice Manuals.

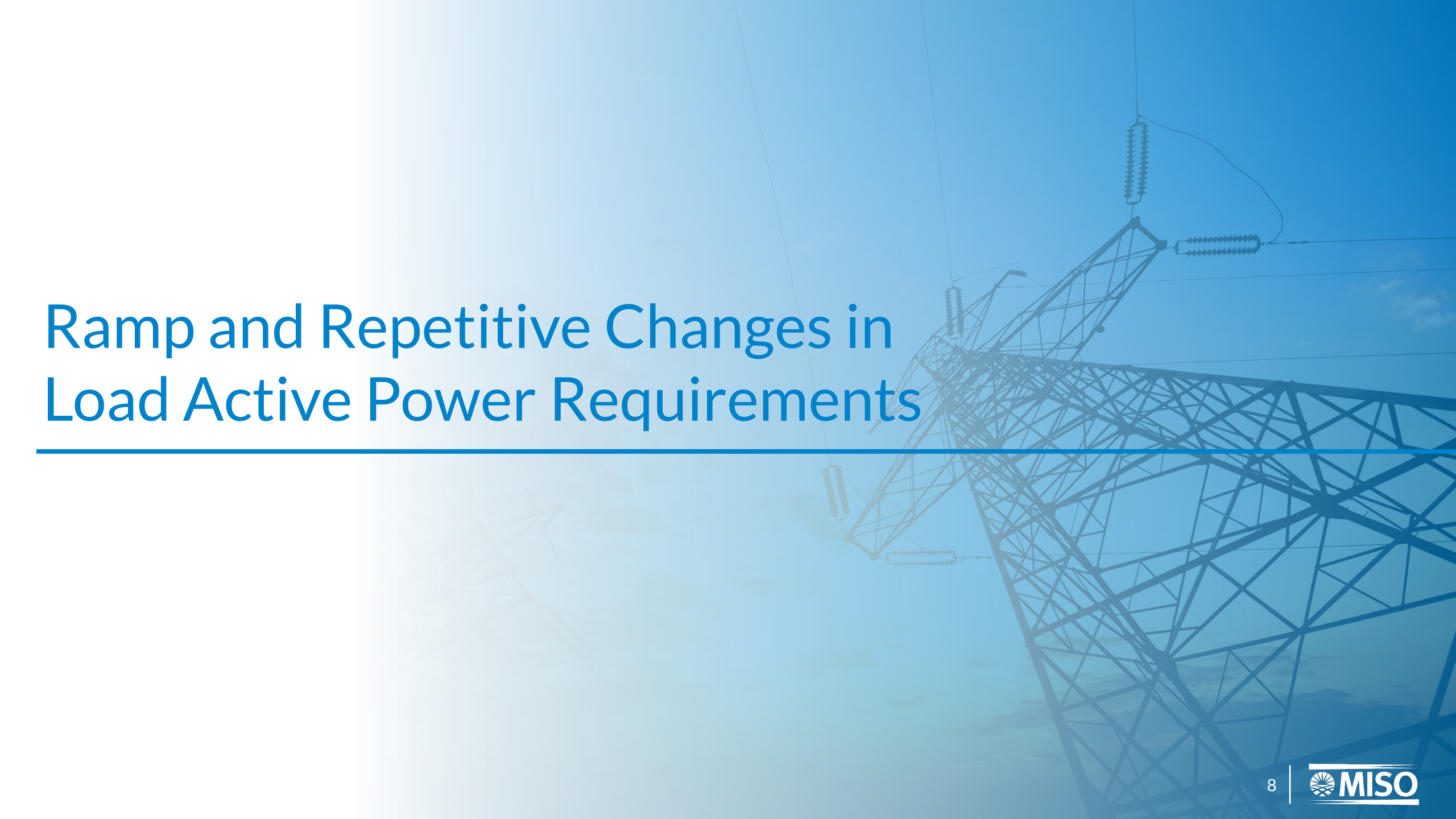
Large Load includes any modification, expansion, or addition to existing load that results in the total aggregated capacity at such single site exceeding 50 MW.

A load is deemed a large load depending on when and if it meets the MW threshold

Large Load threshold: >50 MW as of September 1, 2026

Load Status	Considered a Large Load?	Subject to Interconnection Reliability Requirements?
Load in-service prior to effective date	No	No
Not in-service by the effective date, but reflected in MTEP/EPR	Yes, if >50 MW	Yes, but the requirements allow these projects greater flexibility in how the requirement is met
Not in-service by the effective date and not reflected in MTEP/EPR	Yes, if >50 MW	Yes, with transitional provision

Ramp and Repetitive Changes in Load Active Power Requirements



The Challenge:

Large load ramps introduce rapid, high-magnitude demand changes that challenge system stability, voltage control, and intra-minute balancing of load and generation

- AI training cycles can cause data center load to have persistent changes in load active power and introduce oscillations in the grid
- Large ramps up and down in the intra-minute time-scales introduces risks associated with system balancing
- Industry groups identify fast and cyclical ramping from emerging large loads as a key reliability concern, and MISO's Large Load Interconnection Reliability Requirements outline three focus areas to address this risk

Proposed Requirement:

Responsible entity shall monitor and ensure that net ramp rate of its respective Large Load facility(s) interconnecting to the Transmission System, observed at the transmission interface, does not exceed 30 MW/min ~~and active power oscillation does not exceed 10 MW in a 5-second time window~~

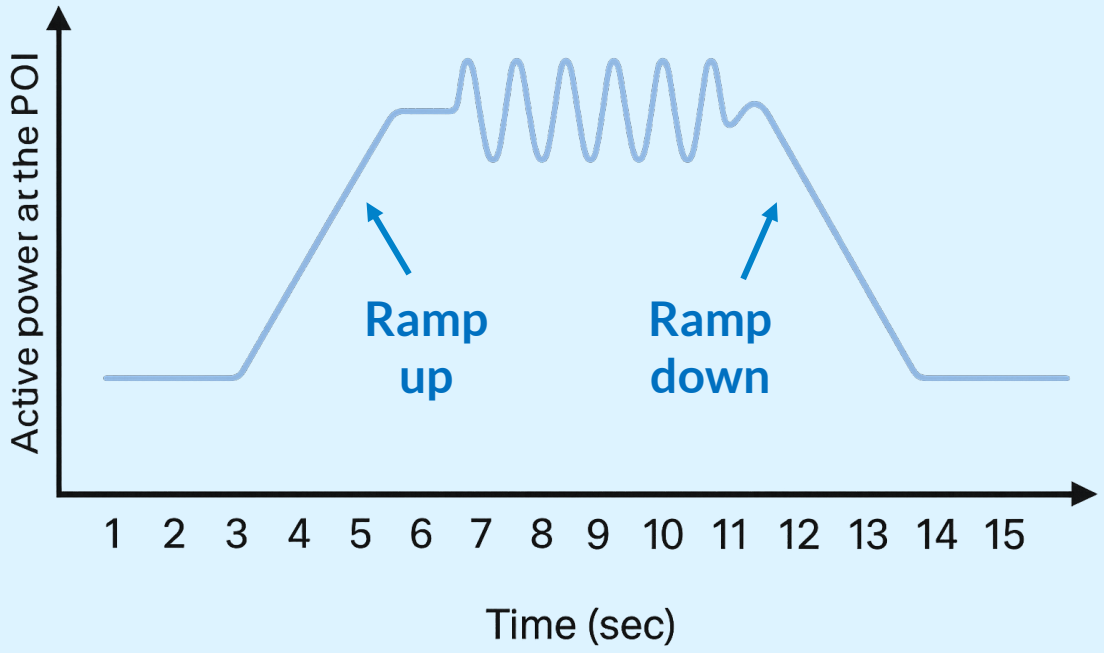
MISO's proposed responsible entities for each requirement:

	MISO	TO, LSE
Ramp rate (increase or decrease) shall be limited to 30 MW/min at the point of interconnection to limit risks associated with system balancing		✓
~~Repetitive changes in load active power shall be limited by 10 MW in a sliding 5 second time window to limit risks associated with system oscillations~~		~~✓~~

TO: Transmission Owner LSE: Load Serving Entity

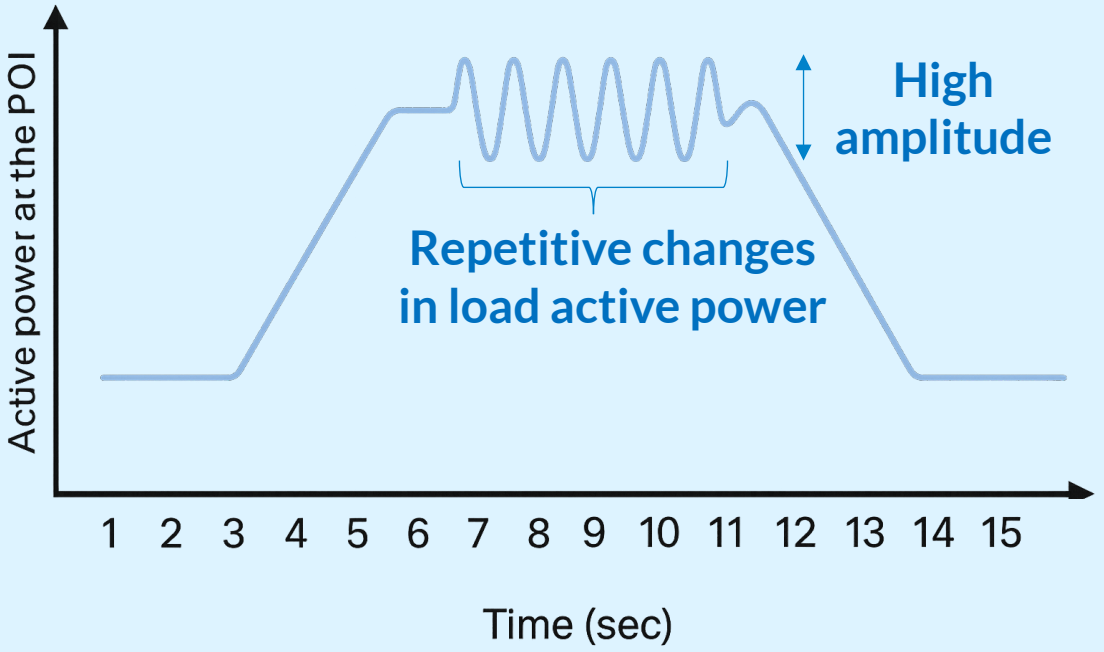
Rapid short-term ramping introduces system risks to balance and stability time scales

Ramp risk in the balancing time scale



Large loads may introduce additional variability in the Automatic Generation Control (AGC) time scale. This effect can increase the risk of inadequate system balancing at the second-to-second level.

Oscillation risk in the stability time scale



Large loads may introduce repetitive changes in load active power at very short time scales. This effect can increase the risk of uncontrollable oscillations and stability issues.

These proposed ramp rate requirements and industry comparisons

MISO Approach

For any tier of large load interconnecting to the transmission system, the net ramp rate observed at the transmission interface shall not exceed 30 MW per minute unless otherwise approved by the Transmission Provider.

Industry Examples

OPERATOR	ACCEPTABLE LOAD VARIABLITY CRITERIA
ATC[1]	Criteria 2: Any Change (increase or decrease) in load>50 MW should be limited to 0.5 MW/s
ERCOT[2]	Once each large load is built, the system operator approves ramp rate based on individual study results for that large load.
SPP	Large loads must limit ramping to no more than 20 MW per minute (unless otherwise directed) and coordinate changes with the transmission operator to maintain system reliability.

1. https://www.nerc.com/globalassets/who-we-are/standing-committees/rstc/whitepaper-characteristics-and-risks-of-emerging-large-loads.pdf
2. 20260114_Order-Revisions to Add the High Impact Large Load Process and Generation Assessment_ER26-247-000
3. 20260114_Order-Revisions to Add the High Impact Large Load Process and Generation Assessment_ER26-247-000

Requested Stakeholder Feedback for the Ramp Requirements



1. How does your organization currently manage ramp-up and ramp-down behavior for large loads?
2. Do you have alternative ramp limits to propose
3. What concerns do you have about implementing ramp-related limits at the time of interconnection?

Data Requirements for Interconnection and Operational Readiness



The Challenge:

Insufficient visibility into large load behavior complicates interconnection studies and operational readiness, underscoring the need for clear data and modeling requirements

- As large load interconnections increase, detailed technical data help ensure reliable system assessments
- Industry research highlights the value of more comprehensive dynamic models to strengthen assessments in planning and operations timeframes
- Use of telemetry technologies with fast sampling capabilities have been highlighted in other areas as a key requirement for monitoring the system
- Large loads can change system conditions rapidly, and unlike traditional demand, their behavior cannot be forecasted accurately using historical load patterns, even when modeled with weather and calendar data in MISO's short-term forecasting system

Proposed Requirement:

Responsible entity shall provide detailed and standardized data for interconnection and operational readiness, including basic facility information, dynamic models, more granular telemetry data, short-term forecasting, and outage data

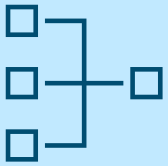
MISO's proposed responsible entities for each data requirement:

	MISO	TO, LSE
Provide basic facility data for interconnection studies and commissioning		✓
Provide power flow and dynamic modeling data for interconnection studies/assessments and commissioning		✓
Provide granular telemetry data for real-time monitoring, post-event analysis, and dynamic model validation*		✓
Provide short-term forecasts and outage data as defined through MISO's forecasting and outage coordination processes*		✓

*To be covered in more detail in the Reliable Operations Workstream
TO: Transmission Owner LSE: Load Serving Entity

MISO's proposed basic facility and modeling data requirements

Basic Facility Data



- ❑ Basic facility data required in the Expedited Project Review Request form (e.g., project name/description, required in-service date and phase-in schedule, expected lead-time, etc.)
- ❑ Large load composition as a percentage of the total rated load (e.g., cooling systems, etc.)*
- ❑ Large load power factor (including if it is leading or lagging)*

Modeling Data

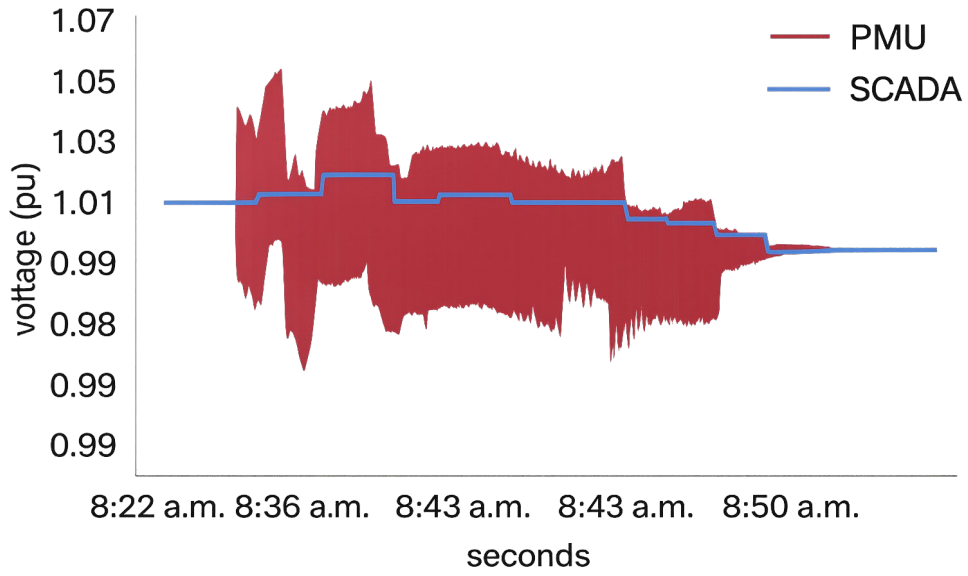


- ❑ Modeling data required in the Expedited Project Review Request form (e.g., monitored element and contingency update files, model updates to Model on Demand and MISO Model Manger, etc.)
- ❑ Power Electronic Reconnecting and Ceasing (PERC1) Load Model for positive-sequency dynamic study (PSDS)*
- ❑ Load model necessary for any potential EMT study*

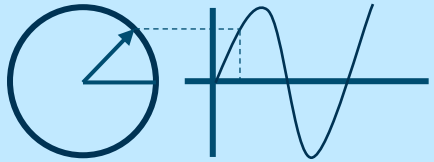
*Data requirements beyond the Expedited Review Process (EPR) | EMT: electromagnetic transient

MISO's proposed telemetry requirements

- Synchrophasors are high frequency (e.g., 30 samples/sec) measurements that are timestamped using GPS clocks
- Provides unique insights in the grid and its dynamics that goes well beyond traditional SCADA
- Industry consensus on the need for PMU requirements (or better) to support real-time monitoring and dynamic model validation (ESIG, NERC, SPP)



Telemetry Data Requirements



- ❑ Phasor measurement unit (PMU) or better
- ❑ Minimum sampling rate of 30 samples/seconds*
- ❑ Details related to measured quantities, data recording and retention, power quality, and infrastructure to be discussed in Reliable Operations Workstream

Figure adapted from https://www.eia.gov/todayinenergy/detail.php?id=5630 | *To be discussed in more details in Reliable Operations Workstream
PMU: phasor measurement unit | GPS: global positioning system | SCADA: supervisory control and data acquisition

MISO's proposed forecasting and outage coordination requirements

Provide operational forecasts and outage data as defined through MISO's forecasting and outage coordination processes. More details will be covered in the Reliable Operations Workstream.

Short-Term Large Load Forecasting



- **Rationale:** Large Loads can change system conditions rapidly, and unlike traditional demand, their behavior cannot be forecasted accurately using historical load patterns, even when modeled with weather and calendar data in MISO's short-term forecasting system.
- Requirements would include day-ahead and real-time components

Planned Outage Notification



- **Rationale:** Ensure that MISO and the applicable Transmission Owner have sufficient time to assess system impacts, maintain reliability, and coordinate outages across the broader transmission network
- Requirements would align with the current outage coordination process

Integration of proposed data requirements in the commissioning process



Interconnection Request

- ✓ Basic facility data submitted and is current
- ✓ Model updates to Model on Demand (MOD) and MISO Model Manger (MMM) are submitted and current
- ✓ Models for EMT studies are submitted and current



Performance verification

- ✓ Performance of measured versus modeled (e.g., MW/MVAR, ramps)
- ✓ Voltage and frequency ride-through responses
- ✓ Telemetry and short-term forecasting requirements are tested and verified
- ✓ Communication protocols between responsible entities are established (for short-term forecasting and telemetry requirements)



In-service

- ✓ Continue to operate consistently with submitted and validated models
- ✓ Notify MISO of any material changes in facility behavior or configuration
- ✓ Support ongoing model validation and conformance assessments; provide updated data when required

EMT: electromagnetic transient | PSDS: positive-sequence dynamic | EPR: expedited review process

Requested Stakeholder Feedback for the Data Requirements



1. Do you have any suggested additions or revisions to the basic facility information requirement?
2. What additional data/modeling requirement at the time of interconnection should be included?
3. Is the level of telemetry granularity sufficient to monitor large loads?
4. What information or lead time do you need from MISO to produce a useful short-term forecast (e.g., notification windows, reforecast triggers)?
5. What concerns do you have about forecast submission obligations: accuracy expectations, update frequency, or confidentiality of submitted data?
6. Are there existing forecasting practices or tools at your facility that MISO should consider when defining the submission format?
7. Do you have any suggested additions or revisions to the outage coordination requirement?

Ride-through Requirement



The Challenge:

Unpredictable large load behavior during disturbances can exacerbate system events, underscoring the need for clearly defined ride-through requirements

- Large loads can disconnect during grid disturbances, amplifying system stress and increasing the risk of cascading events.
- No consistent large-load ride-through standards exist today, leading to widely varying and unpredictable behavior.
- NERC has highlighted gaps in load performance expectations, signaling the need for improved clarity and coordination.
- The industry is transitioning toward standardized, enforceable load-performance requirements to support reliability.

Proposed Requirement:

Large load facilities must comply with defined voltage and frequency ride-through requirements aligned with IEEE 2800 / PRC-029 to avoid large load tripping that could increase the risk of cascading events

MISO's proposed responsible entities for each ride-through requirement:

	MISO	TO, LSE
Meet or exceed MISO-established ride-through performance requirements for transient system events, consistent with standard industry practices.		✓

TO: Transmission Owner LSE: Load Serving Entity

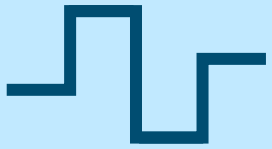
MISO's proposed ride-through requirement framework

Voltage Ride Through



- ☑ Voltage Ride-Through Envelope
- ☑ Performance Requirements During Disturbances
- ☑ Transient Overvoltage (TOV) Ride-Through
- ☑ Consecutive Voltage Disturbance Capability
- ☑ Volts per Hertz (V/Hz) Compliance

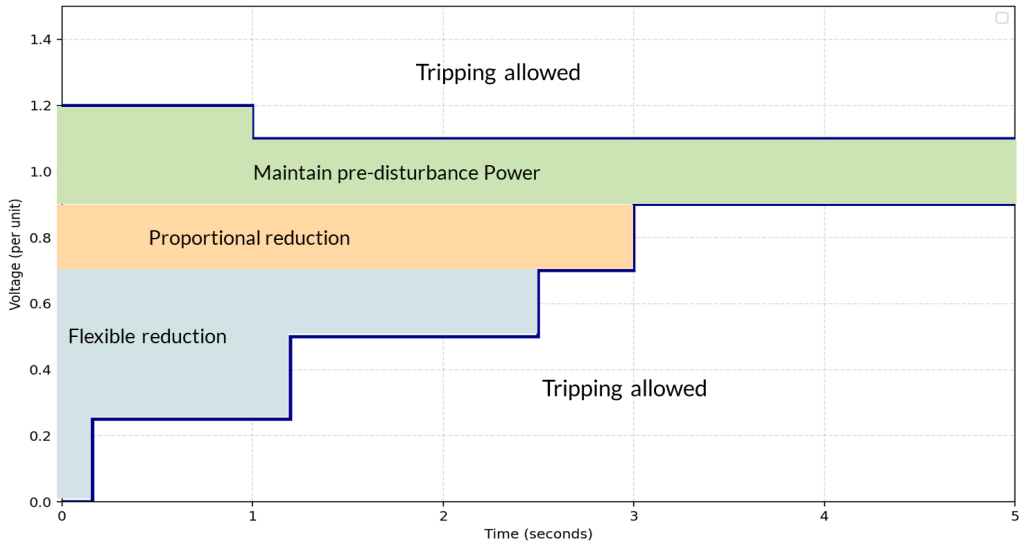
Frequency Ride Through



- ☑ Frequency Ride-Through Envelope
- ☑ Performance Requirements During Excursions
- ☑ Rate of Change of Frequency (RoCoF)

Standards aligned with IEEE 2800 and NERC PRC-029.

MISO’s proposed voltage ride through requirement



0.90 – 1.20 pu	**CONTINUOUS RANGE**	Maintain pre-disturbance active power. Control stability is mandatory. No power reduction is permitted between 0.9 and 1.2 pu.
0.70 – 0.90 pu	**MANDATORY RECOVERY**	Active power reduction is permitted but must be proportional. Restoration of ≥90% power is required within 1s of recovery.
< 0.70 pu	**STABILITY PRIORITY**	Flexible power reduction is allowed to maintain synchronization.

Phase Jump

Remain connected for sudden phase angle changes up to 25° .

V/Hz Limit

Ride through 1.1 pu for 45s or 1.18 pu for 2s.

Consecutive

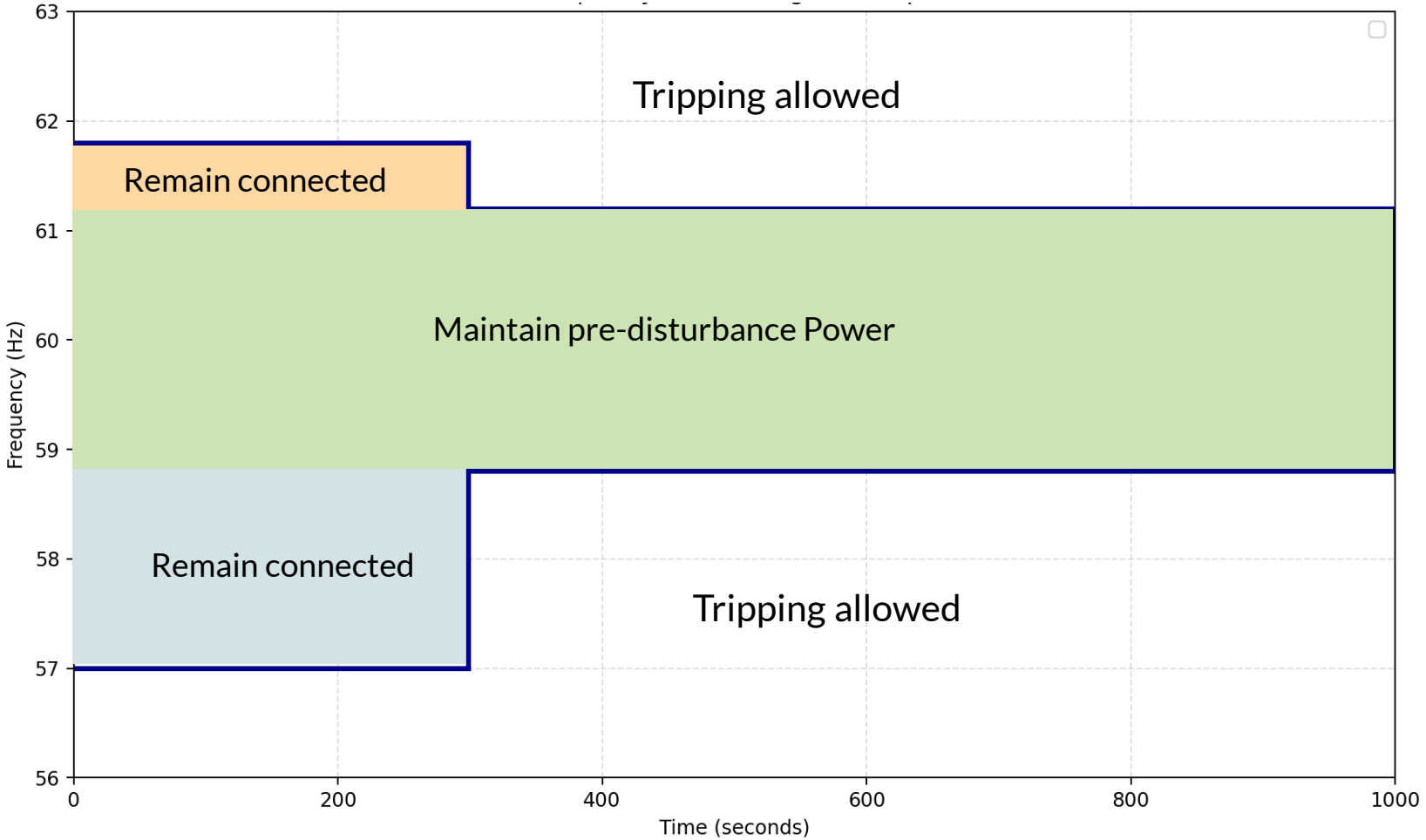
Must handle three voltage disturbances within 10 seconds.

Transient VRT

No tripping for normal system events like faults or switching

MISO's proposed frequency ride through requirement

Envelope, Compliance and Recovery



61.2 – 61.8 Hz

Maintain active power within ±10% of pre-disturbance levels

58.8 – 61.2 Hz (Normal Operation)

Maintain pre-disturbance active power

57.0 – 58.8 Hz

Maintain active power within ±10% of pre-disturbance levels

RoCoF Ride-Through

Remain connected for frequency within frequency ride-through envelop when |RoCoF| ≤ 5.0 Hz/s; coordinate protection with system reliability.

Requested Stakeholder Feedback for the Ride-Through Requirement



1. Do you have alternative proposals for a ride-through performance (voltage and frequency) requirement for large loads during grid disturbances?
2. Should additional expectations be placed on load behavior during disturbances?
3. What concerns do you have about implementing ride-through requirements at the time of interconnection?

Stability Assessment Requirement



The Challenge:

Unpredictable, dynamic large load behavior, weak grid interactions and oscillations, underscore the need for clearly defined stability assessment requirements

- Large loads can disconnect during grid disturbances and introduce rapid power changes, impacting voltage, frequency, and stability
- Power-electronic loads can create control interactions and weak-grid challenges
- Large loads may excite oscillations (forced or sub-synchronous)
- NERC identifies gaps in modeling, planning, and standards for large loads

Proposed Requirement:

The responsible entities shall perform, and implement any mitigation required by MISO, standardized stability assessments to mitigate risks to system stability

MISO's proposed responsible entities for each stability assessment requirement:

	MISO	TO, LSE
Develop EMT screening criteria such as system strength metrics to identify projects requiring targeted EMT studies	✓	
Complete the MISO-established stability assessment framework to evaluate the system impacts of large load interconnections and coordinate study results with MISO.		✓
Review and evaluate study results to assess system reliability impacts	✓	
Identify and submit required transmission mitigation projects for inclusion in the MISO Transmission Expansion Plan		✓

TO: Transmission Owner LSE: Load Serving Entity

MISO's proposed stability assessment framework

1 PSPD Transient Stability

- ☑ Enhanced Load Modeling
- ☑ Targeted Contingency Analysis

2 Forced Oscillation

- ☑ Industry Drivers
- ☑ Comparative Industry Criteria

3 System Strength

- ☑ NSCR Screening*

4 EMT Studies

- ☑ Complex Analysis

5 SSO Screening

- ☑ Risk
- ☑ Impact
- ☑ Industry Screening Practices

NOTE: Use screening and targeted studies, not one-size-fits-all analysis.

* System Strength Metric NSCR will be introduced to stakeholders at the April 28 IPWG meeting

MISO's proposed PSPD transient stability assessment

Enhanced Load Modeling

- Explicitly model dynamic behavior of Large Loads, including ride-through capability
- Utilize detailed load composition modeling to capture power-electronic and motor characteristics

Targeted Contingency Analysis

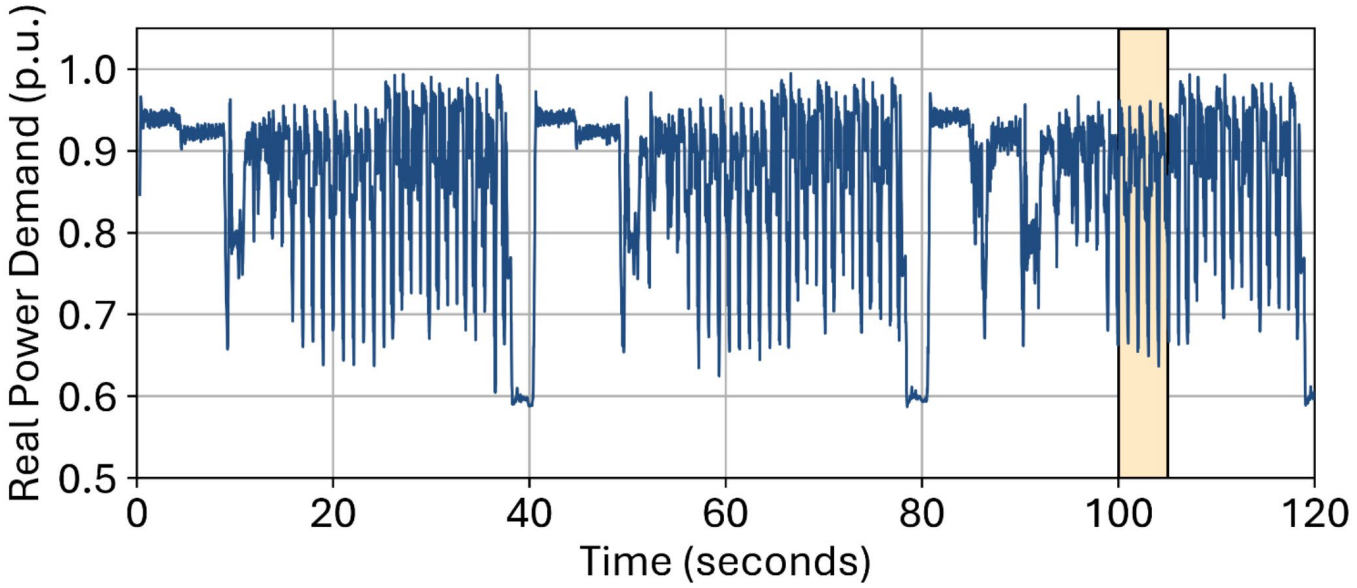
- Perform simulations for the credible loss of large load contingencies
- Evaluate system impact of sudden multi-megawatt load rejection on frequency and voltage

MISO Proposal

All other study procedures, including out-year system topology and fault-clearing sequences, follow existing MISO BPM-20 practices.

Forced oscillation requirement rationale

Industry Drivers



NERC LLTF White Paper

Large loads introduce a new class of forced oscillation risk—they can create, amplify, and propagate oscillations across wide areas, with impacts that are not fully captured by existing planning and standards.

NERC LLTF Characteristics and Risks of Emerging Large Loads

MISO's proposed forced oscillation requirement

MISO Proposal

Standardizing forced oscillation risk management across the footprint.

≤ 10 MW / 5s Window

Industry Examples

OPERATOR	ACCEPTABLE LOAD VARIABLITY CRITERIA
ERCOT	Power shall not repetitively exceed 10 MW in a 5s sliding window.
SOCO	Median change ≤ 1 MW or 1% capacity every 4–6s; P75 ≤ 10 MW.
ATC	Repetitive changes must remain below 25 MW for any period < 5s.
AESO	Variability ≤ 16 kW per 100ms; SSO amplitude ≤ ±160 kW (< 60 Hz).
LIPA	5–55 Hz Band: < 3.5 MW; 0.1–5 Hz (Local): < 10 MW.

MISO's proposed System Strength Screening & EMT Study

System Strength Screening

Identify weak-grid conditions and flag large-load projects that require detailed EMT analysis.

- Identify weak-grid risks (fast transients, control interactions)
- Use NSCR metric
  - NSCR* < 3 → EMT study required
- Aligns with FERC Order 2023 and NERC guidance
- Prioritizes studies; avoids unnecessary EMT analysis

IF NSCR<3

Trigger EMT

EMT Study

Evaluate detailed dynamic behavior and control interactions of large loads to identify risks and define necessary mitigations

- Triggered by low system strength (NSCR < 3)
- Build detailed EMT models (large load + network)
- Assess:
  - Inverter control interactions
  - Fast transient instability
- Compare pre/post project performance

* System Strength Metric NSCR will be introduced to stakeholders at the April 28 IPWG meeting.

Sub-synchronous oscillation (SSO) assessment rationale



Risks

- Large loads can excite series-compensated line resonances.
- Load electronics may add energy instead of damping oscillations.



Impacts

- Reduced damping of sub-synchronous oscillations
- Oscillations may grow or persist, risking instability

MISO's proposed sub-synchronous oscillation (SSO) assessment requirement

MISO's Approach

MISO will continue to rely on existing Transmission Owner (TO) local planning criteria to identify and evaluate SSO risks. Given the limited series compensation in the footprint, assessments are triggered per established TO-specific local screening

Industry Examples

OPERATOR	SCREENING & STUDY THRESHOLD
ERCOT	Requires SSO studies for resources located within six tiers of series-compensated lines.
SPP	Conducts impedance scans at the point of interconnection using EMT models under contingencies up to N-5. Detailed analysis is triggered by identified network resonances that may interact with HILL controls.
Entergy	Requires an SSR study for any new generation (synchronous or non-synchronous) or electronic load near series-compensated lines.
Xcel Energy	For interconnections on series-compensated lines, requires a Subsynchronous Controls Interaction study using PSCAD to ensure proper tuning of IBR/IBL device controls.

Requested stakeholder feedback for stability assessment requirements



1. Is the proposed system strength screening approach appropriate for triggering EMT studies?
2. What study scope (PSPD vs. EMT) is appropriate, and under what conditions?
3. What implementation approach and timeline are reasonable?
4. What challenges or risks do you foresee in applying the proposed study requirements

Feedback questions help ensure the requirements are practical, effective and support reliability

Requirement	Feeback Questions
1. Ramp Limit	A. How do you currently manage ramp-up behavior for large loads? B. Do you have alternative ramp limits to propose C. What concerns do you have about implementing ramp-related limits at the time of interconnection?
2. Oscillation Limit	A. Do you have any suggested additions or revisions to the requirement? B. Are there any concerns regarding coordination with other requirements? C. Are there any concerns with implementing this requirement using existing large load technologies?
3 & 4. Basic Facility Information and Modeling	A. Do you have any suggested additions or revisions to any of the basic facility information requirement? B. What additional data/modeling requirement at the time of interconnection should be included?
5. Telemetry	A. Is the level of telemetry granularity sufficient to monitor large loads?
6. Short-term Forecast	A. What information or lead time do you need from MISO to produce a useful short-term forecast (e.g., notification windows, reforecast triggers)? B. What concerns do you have about forecast submission obligations: accuracy expectations, update frequency, or confidentiality of submitted data? C. Are there existing forecasting practices or tools at your facility that MISO should consider when defining the submission format?
7. Outage Coordination Protocols	A. Do you have any suggested additions or revisions to the outage coordination requirement?
8. & 9. Voltage & Frequency Ride-through	A. Do you have alternative proposals for a ride-through performance (voltage and frequency) requirement for large loads during grid disturbances? B. Should additional expectations be placed on load behavior during disturbances? C. What concerns do you have about implementing ride-through requirements at the time of interconnection?
10. Stability Assessment	A. Is the proposed system strength screening approach appropriate for triggering EMT studies? B. What study scope (PSPD vs. EMT) is appropriate, and under what conditions? C. What implementation approach and timeline are reasonable? D. What challenges or risks do you foresee in applying the proposed study requirements

Stakeholder Feedback Request

- MISO requests feedback on the **Large Load Interconnection Reliability Requirements** by May 4, 2026
- Feedback requests and responses are managed through the Feedback Tool on the MISO website: https://www.misoenergy.org/engage/stakeholder-feedback/

Next Steps



Large Load definition finalized

PAC Meeting:

April 22, 2026



Provide feedback on today's content

Due: May 4, 2026



Review drafts on requirements and discuss tariff language

LLWG Meeting:

May 14, 2026



Review tariff language based off feedback

LLWG Meeting:

June 10, 2026



Finalize tariff language

LLWG Meeting:

June 29, 2026

Send questions or comments to:

LargeLoadProgram@misoenergy.org