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Large Load Centers & Reliability Risk

Data centers and large concentrated load growth as reliability variables.

A single data center campus can now ask for as much power as a mid-sized utility serves. Planning models built on gradual, dispersed load growth were not designed for that, and NERC and FERC have moved from watching to acting. This reference explains where concentrated load creates reliability risk and what the 2026 computational load framework asks of planners and operators.

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Foreword

This professional reference is one of a series Energy Compliance, Inc. publishes for registered entities and the people who run their compliance programs.

I've spent more than thirty years on every side of the bulk electric system. I've operated control centers as a Reliability Coordinator, Transmission Operator, and Power System Operator. I've audited grid facilities and signed off on findings as a senior compliance auditor. I've worked enforcement matters from inside the regulator's process. For the last several years I've advised registered entities directly through the firm I founded.

The entities that do reliability well share a common habit. They take the standards seriously without confusing them with reliability itself. They know that a NERC Reliability Standard is a floor, not a ceiling. They know that compliance is something an auditor evaluates, but reliability is something a system either delivers or doesn't. They prepare for audits by building programs that survive real questions, not binders that look thick.

That's the perspective these references try to share. Each one focuses on a single topic: a standard family, an operational function, a regulatory framework, or an emerging industry challenge. Each one walks through how the topic actually works.

These references are written for the compliance manager who wants to understand the system, not just memorize requirements. For the legal counsel who has to brief a board honestly. For the senior operator who's been told that compliance and reliability are the

same thing and suspects they aren't. And for the new compliance hire who got handed a binder and told good luck.

These references aren't marketing material disguised as content. They're the result of three decades of doing this work and watching it succeed and fail. I've written them in the same voice I use in a control room or in front of a Regional Entity audit team: direct, evidence-grounded, honest about what the standards do and do not require.

Energy Compliance exists because most of the consulting offered to registered entities today is structured for billable hours rather than for outcomes. Every engagement is overseen by a senior practitioner. We don't bring five people to a meeting that needs one. We automate the work that should be automated. We apply senior judgment to the work that requires it. If that approach matches what you're looking for in a compliance partner, the back of this reference has our contact information.

If not, the reference still belongs to you. Take what's useful. Apply it well. And remember the only test that ultimately matters: when the system needs to perform, does it?

Rob Smith

Founder and Principal, Energy Compliance, Inc.

Executive Summary

Data centers are the new generation, except they consume rather than produce. NERC's Large Loads Task Force cites Meta's planned 2 GW AI training facility in Louisiana as one example of a hyperscale load. The reliability framework was not designed around that profile. In my view, planning models built on gradual demand growth are not catching up to step changes fast enough.

NERC is no longer just paying attention. In May 2026 it issued a Level 3 Essential Action alert on computational load. In July 2026 FERC directed NERC to file computational load Reliability Standards by December 31, 2026, and to develop registry criteria it expects NERC to submit by the same date. In October 2026 three new CLO standards passed final ballot, and NERC's Board approved Rules of Procedure revisions, still pending FERC approval, that would create two new registered functions. Every Transmission Planner, Planning Coordinator, Transmission Owner, Transmission Operator, Balancing Authority, and Reliability Coordinator with large loads in its footprint, or expecting them, should be paying attention too.

- **Interconnection approval is not deliverability.** Projects that confuse the two find out the hard way.
- **Regional adequacy does not protect local reliability.** Aggregate margin can be fine while a specific corridor is short.
- **Load concentration breaks average-based planning assumptions.** Models built for gradual growth under-predict step-change conditions.
- **Concentrated load growth concentrates transmission stress.** The constraint shows up at specific lines and substations, not as a general problem.
- **Large loads can leave the system in milliseconds.** In July 2024 a series of normally cleared 230 kV faults was followed by about 1,500 MW of data center load transferring to backup power at once. AI training loads can also swing sharply within a second as workloads shift.
- **The risk at large load centers is uncertainty, not size.** Unknowns in load behavior, ramp rate, and protection settings shape risk in ways aggregate magnitude doesn't capture.

The standards are catching up. Until the new ones take effect, the planners and operators who treat large load as a reliability variable, not a forecast line item, will be the ones who see the problem first.

> **From the Field**
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> A 2 GW campus is a utility-sized load. The framework is recalibrating to that reality.

1 Large Load Centers in the Bulk Electric System Context

This reference looks at large load centers through established reliability concepts: NERC Reliability Standards, NERC technical reports, and the planning assessments that registered entities already run. It is not a compliance guide. It is a primer on how emerging load conditions interact with the reliability obligations that govern Bulk Electric System (BES) planning and operations, and why that interaction now gets so much attention.

The questions that matter are practical ones. How does very fast load addition affect transfer capability, power flow, and stability margins? What happens to resource adequacy when demand arrives before the generation and transmission meant to serve it? How do operators manage demand variability, hold enough reserves, and recover the system quickly when a large load behaves in ways nobody modeled?

1.1 What Has Changed

Large load centers are not new to the bulk electric system. What has changed is the rate and scale at which load now arrives, and that change is large enough to undercut the assumptions behind reliability analysis.

Historically, load growth followed well-defined, predictable patterns tied to population, modest industrial growth, and the local economy. When growth was that predictable, planners could carry it years into the future with reasonable confidence in forecasts, engineering plans, and operating plans. Assumptions about diversity, coincidence, and the dispersal of load across an interconnected system held steady.

Modern large load centers are different. They are often compact, high-density additions concentrated at a handful of transmission substations or corridors. Data centers, electrified manufacturing, hydrogen production, and large electrification projects can each add demand that current grid designs and planning assumptions never anticipated. From a reliability perspective, a load center is defined not by the type of load it serves but by how it interacts with bulk system components and affects reliability performance.

Load is a basic input to every NERC reliability criterion for resource adequacy, transmission planning, and operations. A load center whose magnitude, growth rate, or operating pattern departs sharply from history can affect:

- transmission constraints
- voltage performance
- stability
- contingency recovery

1.2 Concentration Versus Average Growth

The gap between concentrated growth and average growth is one of the central problems. Planners have long assumed that modest regional growth plus a healthy regional reserve margin leaves plenty of room for error. That assumption breaks down when regional growth looks ordinary but the load lands at a few interconnection points. Each point may not look excessive in isolation. Together, rapid growth at several key points drives heavy use of individual lines, thin margins, and power flows that depart from the patterns the plan assumed.

1.3 Load Dynamics and Development Pace

Large load centers also change how load behaves dynamically. Many new loads run relatively flat profiles with little cycling, unlike the highly variable profiles of residential and commercial customers. That raises exposure at system peak and weakens the forecasts and diversity factors that used to supply planning margin. Some large loads also change rapidly or are sensitive to voltage and frequency disturbances, and those behaviors have to be studied in dynamic performance analysis.

Development pace matters too. Transmission and generation projects take years, require regulatory approval, and often face siting problems. Privately developed large loads can move much faster. When they do, the reliability risk comes from the mismatch between construction schedules and system planning, not from anyone's noncompliance with a standard.

1.4 Jurisdictional and Functional Boundaries

Responsibility for the BES is divided among Planning Coordinators, Transmission Planners, Reliability Coordinators, Transmission Operators, and Balancing Authorities according to their functions. A large load center may sit entirely inside one entity's area, or it may stress several boundaries at once and need integrated analysis to understand its full effect. Load interconnection decisions are not always coordinated with broader reliability studies, so a vulnerability may not surface until it shows up as an operating problem.

Large load centers are not inherently unreliable. Trouble comes from the interface: the load's characteristics interact with the system's and push against a constraint nobody had defined. That is why a large load center has to be treated as a significant system variable in normal and contingency operations, not just one more addition to the load forecast.

Chapter Summary

Large load centers represent a real shift in how load growth affects the bulk power system. They are defined by rapid, concentrated growth, both geographic and electrical, that lands on a small number of transmission lines and substations. Load growth has always been a core planning input, but large load centers create new conditions for transmission planning and operations.

2 Data Centers as an Emerging Load Archetype

Data centers have become the leading example of large load centers because of their size, their operating behavior, and how fast they are being built. Data processing facilities have existed for decades. The recent growth driven by cloud computing, artificial intelligence, and cryptocurrency mining has changed how these facilities interact with the bulk power system. From a reliability perspective, they behave in materially different ways from traditional industrial and commercial loads.

NERC now uses the term computational load for this category. Its Level 3 alert gives artificial intelligence training, cryptocurrency mining, and traditional data center uses as examples.

2.1 Size and Concentration

A data center's reliability impact follows from the amount of load and how tightly it is concentrated. Individual facilities often draw hundreds of megawatts of firm load, and they are frequently built as campuses or regional clusters. Connecting multiple buildings to one high-voltage transmission substation, rather than spreading the load across several distribution substations, pushes the potential impact well beyond the serving utility's distribution system.

2.2 Load Shape

Data center load profiles also differ from the legacy patterns they displace. Consumption can run at high load factors with little seasonal or weekly variation. Because the load is close to flat across hours, days, and seasons, it is inherently less diverse than legacy load. It is still there at system peak, when the system is already stressed. That makes it a source of high, inflexible demand at exactly the wrong time.

Flat on average does not mean steady at every instant. NERC's Large Loads Task Force documented an AI training facility whose demand, during its fastest ramp, changed at 1.9 per unit per second for about 250 milliseconds, with transitions between training and checkpoint saving happening in under a second.

2.3 Operational Sensitivity

Data centers are built to protect their own equipment. Their power systems must hold voltage and frequency within tight tolerances and ride through disturbances without interruption, typically using uninterruptible power supply (UPS) systems and backup generators. The interaction between those systems and the BES adds operating complexity. A transfer from grid power to backup can change voltage behavior, fault current, and how the system recovers.

NERC's January 2025 incident review shows what that looks like at scale. On July 10, 2024, a lightning arrester failed on a 230 kV line in the Eastern Interconnection. Auto-reclosing produced six successive faults in 82 seconds, each cleared properly. Coincident with the disturbance, about 1,500 MW of data center load in the area transferred to backup power. No utility disconnected that load; the data centers' own protection and control schemes did. Operators had to act to bring voltage back within normal levels. NERC followed in January 2026 with a review of crypto-mining load reductions in ERCOT, which noted that those facilities typically have no UPS or backup generators and drop within milliseconds of a voltage sag.

> **From the Field**
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> In 2024 every fault cleared as designed. The load left because its own controls told it to, and the operators had not anticipated it.

2.4 Development Pace and Uncertainty

Investment in data centers follows market conditions and technology, not utility planning cycles. Loads can therefore connect faster than the infrastructure built to support them. When several projects land in the same serving area, the combined load can exceed what planning studies assumed, even if each project looked manageable on its own.

Data center load also carries real uncertainty. Nameplate load at interconnection may be well understood, but actual demand changes as computing capacity is added, repurposed, or put to different applications. That makes long-term forecasting and scenario development harder, and uncertainty in ramp rates and peak loads complicates both resource adequacy and transmission adequacy studies.

2.5 Why the Electrical Behavior Is What Matters

The reliability implications of data centers come from their electrical behavior, not their digital function. Other emerging electrified loads with similar size, density, and operating characteristics raise the same concerns. Data centers serve as the archetype here because they concentrate all of these attributes in a way that is highly visible in bulk power system analysis.

Treating the data center as a load archetype, separate from price, economic development, or public policy, keeps the analysis on what the bulk power system experiences under normal and contingency conditions. That separation is what makes a framework-based analysis possible.

> **Chapter Summary**
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> Data centers are big, clustered, flat on average but fast to swing, and quick to protect themselves in ways that can pull large blocks of load off the system at once. Planning and operating assumptions have to change with them. Their reliability impact is set by electrical behavior, not commercial function.

3 Electrification and the Changing Nature of Load Growth

Electrification is changing the nature of load growth on the bulk grid. Load change is now driven by energy shifting from non-electric to electric end uses, at a scale that matters for reliability analysis. Growth from efficiency programs and ordinary economic expansion moved in small increments over the base load. Electrified loads arrive with different patterns: different peak magnitude, load factor, duration of heavy use, timing relative to system peak, seasonal and year-to-year variation, and geography. Those differences undercut reliability analyses that assume base loads with little seasonal or year-to-year fluctuation.

3.1 What Counts as an Electrified Load

For reliability purposes, an electrified load is an industrial process, transportation system, heating system, or other facility powered primarily by electricity. These loads can connect at high or low voltage, draw large currents, and carry operating characteristics unlike conventional load. Emerging uses such as mass transit, hydrogen production, and electric materials processing are not well described by conventional load growth assumptions. When electrification concentrates at one location, the result looks less like scattered customer growth and more like a new large load center.

3.2 Reliability Challenges

Several reliability challenges follow from electrification, and they are closely linked:

- **Resource adequacy assumptions.** Planning reserve margins and capacity market rules were built around load profiles, diversity, and seasonal factors that may not fit new electrified loads.
- **Winter peaks.** Electrified heating can shift or sharpen winter demand.
- **Flatter demand shapes.** Less daily variation means less relief at peak.
- **Changing coincidence between load and resource availability.** New load shapes can line up badly with when resources are available.

Higher demand on equipment designed for different load patterns pushes components past their design basis. Existing equipment may need to be uprated, or service moved to higher voltage. The location of demand can shift too: vehicle charging, for example, can concentrate load at substations originally built to serve industrial or fossil-fueled customers. A full system impact evaluation across the applicable contingencies is the only way to see the effect.

3.3 Pace, Sequence, and Abnormal Conditions

The pace and sequence of electrification add their own complexity. Regulatory, market, and technology forces drive electrification on schedules that often run independent of bulk system

planning. As with data centers, electrified load can grow faster than the infrastructure built to serve it, increasing reliance on existing resources and tightening operating margins under high-load and stressed conditions.

Load behavior under abnormal conditions is a particular concern. Electrified processes may respond to voltage or frequency disturbances differently from conventional load. Some trip almost immediately; others ride through and change the system's dynamic response. Those differences have to be considered in contingency planning, underfrequency load shedding (UFLS) design, and restoration planning, even when the individual loads are not themselves subject to bulk system performance criteria.

3.4 A Qualitative Shift

In my view, electrification does not reduce reliability by itself. Its impact depends on how the new load characteristics interact with the rest of the system, including other resources and operating practices. Given the scale and diversity of the growth, demand and voltage trends alone will not capture the reliability impact. What is needed is system-level analysis of specific load characteristics: voltage level, power electronic behavior, operating schedule, and peak timing for heating, cooling, transportation, and industrial loads.

Electrification is a qualitative shift in load characteristics, not just a quantitative increase in load. Reliability analysis built on that understanding will keep pace with a changing system. Electrified load growth should be treated as a system-wide phenomenon and carried into reliability analysis across every time frame.

> **Chapter Summary**
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> Electrification introduces new classes of load with different operating patterns and timing. That changes the assumptions behind resource adequacy, transmission performance, and how the system behaves under stress. Reliability assessments need to look past the headline load growth number to the characteristics of concentration, timing, and operation.

4 Transmission System Impacts of Concentrated Load Growth

Load that grows in concentrated fashion around a large load center has several adverse effects on the transmission system: higher power flows, less spare capacity on lines, and heavier reliance on critical components. Aggregate load growth is a standard transmission planning input. The localized growth seen around large load centers is not always captured by regional aggregates, and the transmission system is often the first place a constraint is violated when a large load center emerges.

4.1 Local Loading at the Point of Interconnection

The transmission impact of a single large load center starts at its point of interconnection. A large load at or near a bulk transmission substation can substantially raise base-case loading on lines, transformers, and interfaces. Even under normal conditions, the added flow can erode margin below thermal, voltage, and stability planning criteria. Under contingency conditions, the reduced margin can turn into overloads or voltage violations.

4.2 Wide-Area Flow Changes

Concentrated load growth can change power flow patterns across a wide area, well beyond the load's neighborhood. New large loads can raise an area's net imports, reverse historical flow directions, and push more power over long transmission lines. That can activate interface constraints that were never stressed before and create new problems for generation dispatch and resource adequacy. The change deserves careful study for its effect on transmission reliability across the interconnection.

4.3 Voltage Performance

Voltage performance is a major planning concern. Large load centers with high reactive demand tend to depress voltage, especially in weak areas or at the end of long lines. Voltage support may be remote or limited to fixed shunts, neither of which can keep up with large concentrated load additions. In those cases the load additions can leave the system more exposed to voltage and dynamic instability, particularly at peak load, after the loss of shunt reactive support, or during system recovery.

4.4 Timing and Interim Operations

Transmission projects carry long lead times, from simple upgrades to major reinforcements. Loads may therefore connect before the needed transmission is in service. Planners and operators then rely on interim operating measures until the new facilities provide the needed margin. That is not necessarily a reliability crisis, but it raises the chance of delivery

disturbances and reduces the system's ability to provide redundancy or absorb other unexpected events.

4.5 Cumulative Effect of Loads in Close Proximity

The cumulative effect of several large load centers near each other is one of the most important transmission issues today. Each addition may pass its own interconnection study. The combined effect of multiple loads close together, built up over several planning cycles, can be much larger. Evaluating that effect requires coordination across system-wide planning; it is rarely a local issue confined to one interconnection request.

Large load concentrations belong in bulk system planning studies as concentrations, not as a string of individual customer additions. They are still measured against existing planning criteria and performance standards, but they reflect a system configuration that differs from the one those criteria were first applied to.

> **Chapter Summary**
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> Concentrated load growth raises facility loading, changes power flows, and erodes reserve and voltage margins. Because the impact is local, it is not always visible in an assessment of load totals, especially when the load arrives faster than the transmission needed to serve it.

5 Resource Adequacy and Capacity Alignment Challenges

Large load centers can materially affect resource adequacy by changing the magnitude, shape, and duration of system peaks, and in doing so they challenge established capacity planning assumptions. Resource adequacy planning exists to make sure the system has enough generation and demand-side capacity to serve forecast peak load plus required reserves across a range of scenarios. Large load centers can upset that balance even when the regional reserve margin looks comfortable, because their growth and peak demand can arrive far faster than normal.

5.1 The Timing Mismatch

The central resource adequacy challenge is the mismatch between load growth and resource development. New generation takes years to move from planning to service, and siting, permitting, financing, and interconnection can stretch that further. A large load can move from concept to service much faster, driven by private investment and technology demand. In the meantime, existing resources run harder and longer, and the reserve margin available in the near term shrinks.

5.2 Load Shape and Capacity Accreditation

These load characteristics also affect capacity accreditation and planning assumptions. Many large loads run at high load factors and offer little flexibility, so they are fully present at peak. They do not provide the coincidence relief of a diverse residential and commercial mix. A modest addition of large load can therefore have a disproportionate effect on required capacity relative to its share of energy.

5.3 Geography and Deliverability

Geographic concentration matters too. Resource adequacy is typically evaluated at the regional or Balancing Authority level. A region can have enough total generation to meet peak demand while transmission limits keep that capacity from reaching the load. Delivering adequate capacity to large load areas during system stress or transmission outages is a reliability concern in its own right.

5.4 Interaction With the Changing Resource Mix

The changing resource mix compounds the problem. As variable resources make up more of the fleet, the coincidence between demand and resource availability matters more. Large loads with flat demand shapes increase reliance on the most dependable resources during peak hours, even when nameplate capacity looks sufficient, and that shifts planning sensitivities and risk.

5.5 Uncertainty in the Forecast

Uncertainty is more pronounced in resource adequacy analysis for large load centers. The load forecast represents planned load, and it changes as new load is added, operating schedules expand, or facilities are repurposed. Planners have to evaluate a range of possibilities. Underestimating future growth or the rate of peak increase can erode transmission and capacity margins and, with them, delivery reliability.

None of this means current planning methods are inadequate. It means planners need a better understanding of how large load centers interact with system capacity under deliverability constraints. Resource adequacy assessment remains a critical reliability tool. Large, concentrated loads raise the need to keep load growth, resource development, and delivery capability in closer alignment.

Chapter Summary

Large load centers can raise peak demand, reduce load diversity, and pull load growth out of step with resource additions, all of which affect resource adequacy. Changes in the resource mix can make it harder still to deliver capacity the way planning assumed. Adequacy has to be judged at the location as well as the region.

6 Operational Reliability and Real-Time System Impacts

Some aspects of large load center operation are dynamic and short-term, and they don't fit neatly into the long-term view of planning assessments. Planning studies set the design envelope for serving load reliably under expected conditions. Actual operating conditions change constantly with load behavior, system configuration, resource availability, and unexpected events.

6.1 Load Volatility and Ramping

Load volatility and fast ramps are now an operating problem. Many large loads run fairly flat profiles, but some change level quickly for internal reasons, and any of them can drop suddenly in response to a power quality disturbance. Fast changes in large loads affect Area Control Error (ACE), frequency response, and generator dispatch. The challenge is greatest when margin is smallest. The predictability of a load matters at least as much as its size.

6.2 Frequency Performance

Adding large amounts of load makes the system more susceptible to frequency deviations after major disturbances, especially if regulating reserves do not keep pace. After the loss of generation or major transmission, large concentrated loads sit in the path of frequency decline, and their response affects how deep and how fast that decline runs and how underfrequency load shedding performs. UFLS schemes are designed to arrest frequency decline, but their effectiveness depends on how the load is distributed and how it behaves. A simultaneous loss of large load creates the opposite problem: frequency and voltage both rise, as NERC's 2025 incident review describes.

6.3 Voltage Control and Reactive Power

Large load centers often carry high reactive demand and voltage sensitivity, which directly affect real-time voltage support. Operators may need to adjust reactive resources more often to stay within voltage limits during faults or at peak load. The effect is strongest in weak parts of the grid and at the end of long lines serving large load additions.

6.4 Real-Time Contingency Analysis

Real-time contingency analysis has to account for large load centers and how they shape the post-contingency state. With higher base-case loading, margins shrink and contingencies that were never limiting can become limiting. The control room has a narrower operating range and less time between control actions. NERC's Level 3 alert asks Transmission Operators, Balancing Authorities, and Reliability Coordinators to establish Interpersonal Communication

capability and joint operating procedures with computational loads, to improve situational awareness during planned and emergency conditions.

6.5 System Restoration

Large load centers can strongly affect recovery after major disturbances. The sequence and priority of load restoration are critical to synchronizing generation safely and holding voltage stable during restoration. Picking up a large load center during blackstart or partial restoration, when generation and transmission margins are limited, carries significant risk.

Real-time operations show how sensitive the system is when large concentrations of load interact with constantly changing system and contingency conditions. Planning standards describe the conditions under which the system is expected to be reliable. Operations reveal how much of that margin is left.

Chapter Summary

Large load centers affect load forecast accuracy, frequency response, voltage management, and real-time contingency analysis. High load concentrations shrink the operating space and make the system more sensitive to disturbances, especially under high transfer conditions.

7 Reliability Risk, Uncertainty, and Assessment Frameworks

A common misconception is that large load centers are riskier because of the size of the load. The real driver is uncertainty: what might go wrong, and when, are unknowns in bulk system analysis and therefore unknowns in the reliability calculation. Reliability analysis manages risk under normal conditions, expected contingencies, and rare but plausible events. Large load centers add risks that are hard to foresee and that complicate analysis when load growth or system configuration departs from expected or historical patterns.

7.1 Forecast Uncertainty

Load forecast accuracy is one of the main sources of uncertainty. Most forecasting models rely on demographic and economic trends and past consumption. New load centers, especially those tied to technology and industrial capital investment, may not follow those trends. Forecasting when a new load center will arrive, how large its peak will be, how fast it will grow, and what its ultimate capacity will be is inherently imprecise. When those assumptions break, the long-term forecasts behind detailed planning studies come into question.

7.2 Scenario Analysis

Scenario analysis is the main tool for handling that uncertainty. Reliability studies should evaluate a range of load growth scenarios to see how the system performs under different conditions. The substations that serve large load centers become critical components, and planners may need more judgment in choosing scenarios, especially high-growth scenarios or cases where development accelerates. The goal is not to predict the probability of a particular event but to see how system behavior changes as each assumption varies.

7.3 Interaction With Other System Changes

Large load centers interact with other changes on the system: a shifting generation mix, retirement of older baseload and peaking units, growth in inverter-based resources, and changing interregional flows as new high-voltage transmission allows more energy to move between regions. Looking at loads, resources, and transmission separately will not show the whole picture.

7.4 Planning Risk and Operational Risk

Reliability assessment usually distinguishes planning risk from operational risk. Planning risk asks whether the system is designed to meet all performance criteria under stated conditions. Operational risk is the likelihood that actual conditions approach or breach those criteria. Large load centers tend to raise both, because they reduce margin across system components and

make the system more sensitive to unexpected conditions. The planning criteria can be met while greater variability and unpredictability in load raise operational risk.

7.5 Deterministic and Probabilistic Methods

Risk tied to uncertain load growth and system parameters now gets more attention across the industry. Probabilistic methods let planners assess both the likelihood of an event and the effect of uncertainty in load growth and system parameters. NERC's planning standards are largely built on deterministic criteria. Adding probabilistic analysis gives a better picture of the risk large load centers create and of where a system stands relative to that risk.

Reliability risk is often misread as the occurrence of reliability events. It is better understood as a measure of how the margin between system capability and system stress is changing as conditions evolve. Large load centers can change that margin quickly by concentrating load and creating a need for grid development faster than it can be delivered. The principles of reliability risk still apply, as long as the changing risk drivers are properly accounted for.

Chapter Summary

Large load centers are a new source of risk because of uncertainty in load forecasts, timing, and interaction with other system changes. That uncertainty erodes planning and operating margins and makes the system more vulnerable to unexpected variation. Scenario analysis and probabilistic methods help show what large load centers do to risk on the bulk electric system.

8 Interconnection, Deliverability, and System Boundaries

Integrating large load centers into the bulk electric system requires a clear line between interconnection capability and deliverability, and a clear view of where system boundaries fall.

8.1 Interconnection Is Not Deliverability

An interconnection study asks whether a new load can connect to the transmission system without violating planning criteria. It looks at the system at the time of connection. It typically examines steady-state thermal limits, voltage, and stability concerns that arise with the added load, and many large load additions turn out to require transmission reinforcement or operating limits on lines and transformers to meet planning criteria. What an interconnection study does not do is guarantee that the load will be reliably served as system conditions change over time.

Deliverability extends transmission reliability to a different question: is there enough transmission capability to move power from where it is produced to where it is needed during stressed conditions? Large load concentrations create deliverability problems where outside supply is hard to bring in, where interfaces are constrained, or where a few circuits serve a large load. In those places the capacity that can actually reach the load may be limited even though regional capacity looks ample.

8.2 Boundaries Between Planning Areas

Planning and operating responsibilities are divided among functional entities and subregions, each with its own boundaries and assumptions. A large load center can be fully analyzed within one planning area while its effects reach other areas and even other regions. If analyses are not coordinated across those boundaries, the cumulative effect of large load centers may stay hidden until near real time, when it becomes obvious.

8.3 Transmission and Distribution Boundaries

Boundaries also exist between BES facilities and distribution facilities. Some large load centers connect directly to the bulk transmission system. Others are served from high-voltage distribution systems that, from a bulk system perspective, are significant parts of the electric system in their own right. It is not always clear where transmission ends and distribution begins. A large load anywhere on the system still matters to bulk system voltage and contingency response.

NERC's proposed registry criteria draw that line by size and voltage. The Rules of Procedure revisions approved by NERC's Board on October 8, 2026, would register Computational Load Owners and Computational Load Operators for computational load sites with a total connected

load of 50 MW or more supplied through equipment connected at 100 kV or above. The criteria still need FERC approval.

8.4 Abnormal Conditions

Large load centers also interact with system boundaries during abnormal conditions such as restoration and islanding. Whether large concentrated loads can be served or shed during partial system conditions affects restoration sequencing, frequency control, and voltage recovery. Those questions reach well beyond a basic interconnection study and call for a system view of how large loads behave in those conditions.

Chapter Summary

Passing an interconnection study is not the same as being reliably served over time. Deliverability under stress, coordination across planning boundaries, and the behavior of large loads during restoration all determine the real reliability risk. Interconnection processes are the foundation; the risk is set by how the load behaves relative to system interconnections, resources, and transmission capability as conditions change.

9 Regulatory, Oversight, and Reliability Perspective

When this reference was first written, the regulatory posture on large loads was awareness and coordination. That has changed. Between 2025 and 2026, NERC and FERC moved from studying large loads to directing specific actions and writing mandatory requirements. The underlying principle has not changed: the concern is not the type of load, but its effect on established reliability metrics and how the associated risk is managed.

9.1 How the Framework Applies

NERC Reliability Standards apply to registered entities based on the functions they perform. Large load centers do not yet create new requirements on their own; none of the proposed CLO requirements is in effect. They change the conditions under which existing planning, operations, and emergency requirements have to be met. Higher load concentration can reduce performance margins and so affect compliance with the standards that already apply, including the TPL-001 planning performance requirements and the FAC-001-4 and FAC-002-4 interconnection and study requirements.

That is now changing. The proposed Computational Load Owner and Computational Load Operator functions, and the CLO standards described below, would bring the owners and operators of large computational load sites into the registered community for the first time.

9.2 What NERC Has Done

NERC's actions since 2025 build on one another:

- **July 2025.** The Large Loads Task Force published *Characteristics and Risks of Emerging Large Loads*, which set a working definition of large load and documented the behaviors described in Chapter 2.
- **September 9, 2025.** NERC issued a Level 2 alert, *Large Load Interconnection, Study, Commissioning, and Operations*. From the responses, NERC found that entities generally did not have sufficient processes, procedures, or methods for these loads, and it published an aggregated report in March 2026.
- **March 2026.** The Large Loads Working Group published *Assessment of Gaps in Existing Practices, Requirements, and Reliability Standards for Emerging Large Loads*.
- **May 4, 2026.** NERC issued a Level 3 Essential Action alert on computational load, covering modeling, studies, instrumentation, commissioning, operations, protection, and control. It went to Transmission Planners, Planning Coordinators, Transmission Owners, Balancing Authorities, Reliability Coordinators, and Transmission Operators, with acknowledgment due May 11 and reporting due August 3, 2026. In May NERC also published the reliability guideline *Risk Mitigation for Emerging Large Loads*.

- **October 2026.** The three Project 2026-02 standards passed final ballot, and NERC announced on October 15 that they would go to the Board of Trustees for adoption. On October 8 the Board approved the Rules of Procedure revisions establishing the Computational Load Owner and Computational Load Operator functions, subject to FERC approval.

A Level 3 alert is not a Reliability Standard. It requires acknowledgment and reporting under Section 810 of the Rules of Procedure, but it does not make the Essential Actions themselves mandatory, and no penalty attaches to not implementing them. It also does not excuse a failure that independently violates an approved standard.

> **From the Field**
>
> In my view, the Level 3 alert's seven Essential Actions are, in practice, a preview of what an auditor will ask once the CLO standards are in force. An entity that can show it built the data request list, revised its qualified change definition, and stood up communications with its computational loads in 2026 will be better placed for its first audit.

9.3 The Level 3 Essential Actions in Brief

The alert asks for seven things, summarized here:

1. Transmission Planners and Planning Coordinators develop a detailed list of modeling data, settings, and parameters needed from computational loads, based on the PERC1 model or one with equivalent or better capability, and Transmission Owners reflect it in facility interconnection requirements.
2. Transmission Planners and Planning Coordinators study their systems for computational load, including operating limits before voltage or frequency instability, vulnerable areas, and credible Contingencies in which aggregate loss or reduction of computational load causes planning criteria violations.
3. Planning Coordinators revise their definition of "qualified change" to cover load growth, changes to settings or configuration, and repurposing of a computational load.
4. Transmission Owners establish a commissioning process for computational loads.
5. Planners and Transmission Owners study and implement corrective actions so that normally cleared non-bus faults do not cause non-consequential loss of firm computational load.
6. Transmission Owners install and use dynamic fault recording at computational load facilities.
7. Transmission Operators, Reliability Coordinators, and Balancing Authorities establish Interpersonal Communication capability and joint operating procedures with computational loads.

9.4 What FERC Has Done

On July 16, 2026, FERC issued an order in Docket No. RD26-7-000 (196 FERC ¶ 61,031) under section 215(d)(5) of the Federal Power Act. It directs NERC to file, by December 31, 2026, one or more new or modified Reliability Standards addressing the reliability risks of integrating computational loads, and, under section 215(f), to develop Rules of Procedure

revisions, including registry criteria for computational load entities, which FERC expects NERC to submit by the same date. NERC must also file a workplan by March 1, 2027, describing next steps for additional computational load standards.

The order followed the Secretary of Energy's October 23, 2025 proposal, under section 403 of the Department of Energy Organization Act, that FERC consider reforms for the timely and orderly interconnection of large loads to the transmission system. FERC docketed that proposal as RM26-4-000.

9.5 The Proposed CLO Standards

Project 2026-02 produced three new standards and revisions to FAC-001 and FAC-002 (FAC-001-5 and FAC-002-5):

Standard	Title	Applies to
CLO-001-1	Computational Load Interconnection, Studies, & Modeling Data	Computational Load Owner, Planning Coordinator, Transmission Planner, and Transmission Owners, Distribution Providers, and Generator Owners with a Computational Load Site interconnection or study agreement
CLO-002-1	Computational Load Operational Data and Communications	Computational Load Owner and Operator, Balancing Authority, Transmission Operator, Reliability Coordinator
CLO-003-1	Computational Load Protection Coordination & Disturbance Monitoring	Computational Load Owner, Transmission Owner, Distribution Provider, Generator Owner

Each applies to Computational Load Sites with total connected load of 50 MW or more supplied through equipment connected at 100 kV or above. As of this writing they have passed final ballot but have not been adopted by NERC's Board or approved by FERC, so they are not yet enforceable, and their effective dates will follow from the implementation plans once approved. Check the Project 2026-02 page before relying on their status.

9.6 RTOs, ISOs, and the States

RTO and ISO planning, interconnection processes, and market rules also shape how large load concentrations are managed, and their technical studies are often the first place a problem shows up. States are acting as well. In Texas, Senate Bill 6 (89th Legislature) directs the Public Utility Commission of Texas to set standards for interconnecting large load customers in the ERCOT region, with a demand threshold of 75 MW unless the commission determines a lower threshold is necessary. The PUCT adopted those standards as new 16 TAC §25.194, Large Load Interconnection Standards (Project No. 58481, order filed September 18, 2026; effective October 8, 2026).

9.7 Information Flow Is the Real Gap

One of the biggest challenges is information flow and coordination, not control. Many large loads originate as customer developments, outside formal planning processes, with no clear picture of their effect on the utility's transmission and distribution systems. Every affected utility, planner, and operator has to know about emerging load centers and account for them. Without timely, accurate information, risks build unnoticed and cumulative effects go uncounted until it is too late to head off the problem. NERC's own Level 2 findings bear this out: most responding entities did not coordinate with large load entities when gathering the information NERC requested.

Reliability oversight and policy advocacy are different things. Reliability organizations and regulators exist to make sure risk to the grid is understood and that the necessary countermeasures are in place. They do not decide a region's economic development or the technology deployed behind the meter. For large load centers, the focus stays on what happens to the transmission and distribution systems, not on the commercial drivers.

Chapter Summary

Existing Reliability Standards still apply, and they are being supplemented. A Level 3 alert, a FERC directive with a December 31, 2026 deadline, new registered functions, and three new CLO standards mean the owners and operators of large computational loads are about to join the registered community. Transparency, coordination, and a shared understanding of how large load centers behave on the bulk electric system will decide how well that transition goes.

10 System Resilience and Long-Term Reliability Considerations

Large load centers affect both short-term reliability risk and long-term system resilience. Planning practice addresses reliability largely through deterministic criteria. Resilience covers a broader set of concerns: low-probability, high-impact events, deep uncertainty, and restoration after outages. Large load centers touch all of them, so they need to be studied.

10.1 Reduced Reserves Over Time

One long-term effect is reduced operating and planning reserve. Large load centers concentrate demand and drive heavier use of existing transmission and distribution facilities. That can mean more hours operating close to limits with less reserve. A system can meet current standards while carrying thin margin for unusual events or weather-driven forced outages. The long-term cost of running that way is less tolerance for the unexpected, more severe consequences when disturbances happen, and harder restoration.

10.2 Flexibility

System flexibility is the system's ability to respond to dynamic change: short-term swings in load, changes in resource output, and changes in configuration. High, relatively inflexible demand at large load centers limits flexibility under stress, at the same time other trends, such as more variable resources and fewer synchronous units, are changing the system.

10.3 Extreme Events

Extreme events are another lens on long-term reliability. Severe weather, plant or fuel supply failures, and coincident equipment failures all test the grid. Large load centers keep demand high at exactly the times resources and lines are most stretched. Their geographic concentration also increases common-mode exposure, such as shared lines at a substation or a single substation outage.

10.4 Restoration and Recovery

Restoration shows the resilience implications clearly. The order and pace of load restoration after a major disturbance matter for frequency and voltage stability. A large concentrated load can be a major restoration step that has to be coordinated carefully to avoid further instability. As large load centers become more common, they will play a bigger role in restoration planning.

10.5 How the Risk Shifts

Over the long term, large load centers change a system's overall risk profile. Demand alone may not be the controlling factor. The risk at a large load center differs from the risk at smaller

ones because of location, timing, equipment design, and how those factors interact across the system. That is why comprehensive system models and planning methods that can represent new load characteristics are needed.

Chapter Summary

Large load centers affect long-term reliability through reduced margins, reduced flexibility, and altered system response during disturbances and restoration. Concentrated, sustained demand can make disturbances more severe and restoration more complex. Long-term impact belongs in any assessment of system resilience as load conditions change.

11 Synthesis of Reliability Implications and System-Level Perspective

The preceding chapters show that a large load center's effect on reliability comes from the combination of load concentration, load profile, system constraints, and uncertainty across different time frames. Seeing the full effect requires a system-wide view.

11.1 Location Matters

Locational analysis is becoming central to regional reliability planning. Large load centers show that regional indicators such as load growth and reserve margin do not capture all the risk at a given location. Transmission constraints, deliverability limits, and voltage problems can appear inside regions that are adequately supplied in aggregate. Reliability analysis has to look at the region and at the location.

11.2 Aligned Assumptions

Assumptions also have to line up across planning functions. Load forecasting, transmission planning, resource adequacy analysis, and operations planning work on different horizons, and their assumptions are not always synchronized. Large load centers expose those inconsistencies. If assumptions about load shape or peak differ between functions, the problem may not show until reliability margins are already under pressure.

11.3 Integrated Analysis

The growing number of large load points and the changing resource mix make integrated analysis more necessary than ever. Sustained high demand during periods of low resource performance can expose the system even when it meets every planning criterion. Capacity margins that look adequate at the planning level may not hold up under stressed conditions.

11.4 Uncertainty and the Role of Load

Uncertainty runs through every one of these risks. As load centers grow, the uncertainty in their voltage behavior, load factor, and future expansion cannot be handled with deterministic assumptions alone. Current methods offer the right tools, but the significance of these loads calls for deeper scenario and probabilistic analysis, and for updating existing criteria where needed.

Large load centers confirm a basic principle of the bulk electric system: reliability is an emergent property of a complex system. Loads, like generators and transmission lines, shape system performance through their physical and operational interaction with the grid. Treating loads as

active participants in system operation, not just end points, changes how reliability is analyzed. The new CLO standards formalize that idea by giving computational load owners and operators their own obligations.

Chapter Summary

The effects of large load centers on the BES are cumulative and interconnected, not the product of any single high-load location. Location-specific analysis, consistent planning assumptions, integrated resource and transmission planning, and explicit treatment of uncertainty are all needed.

12 Concluding Observations on Large Load Centers and Reliability Risk

Large load centers represent a fundamental change in how demand interacts with the bulk electric system. This reference has treated them as reliability drivers that affect system performance, margin, and risk in measurable ways, across transmission planning, real-time operations, and long-term planning.

12.1 Concentration, Timing, and Location

The central thread is that reliability impact depends more on concentration, timing, and location than on the raw size of load growth. Large load centers create stress points that can undercut a system-wide picture of reliability. Reliability has more than one dimension. Deliverability, performance under stressed and contingency conditions, and location-specific measures of margin all have to be considered alongside system-wide indicators. Large load centers also amplify other changes, such as the shift to inverter-based resources and changing transmission use, which is why I favor system-wide planning over project-by-project review.

12.2 Uncertainty

With ramp rates, peak loads, and development timelines this uncertain, planning methods have to account for uncertainty explicitly.

12.3 Reliability Is Dynamic

Large load centers are not, by themselves, a reduction in reliability. With sound analysis and a system view, their risks can be quantified and managed within established reliability bounds. What they remind us of is an old principle: reliability is dynamic. It changes with system conditions, technology, and customer load. The conditions a system operates under can change almost overnight. Planners and operators need to revisit their assumptions, make sure the right information is developed and available, and apply proven analysis to conditions that keep evolving. The 2026 computational load framework gives them a structure for doing that. It does not do the work for them.

Glossary

Term	Meaning in this paper
Adequacy	The ability of the electric system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements. (NERC Glossary)
Balancing Authority (BA)	The responsible entity that integrates resource plans ahead of time, maintains Demand and resource balance within a Balancing Authority Area, and supports Interconnection frequency in real time. (NERC Glossary)
Balancing Authority Area	The collection of generation, transmission, and loads within the metered boundaries of the Balancing Authority. The Balancing Authority maintains load-resource balance within this area. (NERC Glossary)
Bulk Electric System (BES)	Unless modified by the inclusions and exclusions in the NERC definition, all Transmission Elements operated at 100 kV or higher and Real Power and Reactive Power resources connected at 100 kV or higher. It does not include facilities used in the local distribution of electric energy. (NERC Glossary, summarized)
Computational Load Owner (CLO) and Computational Load Operator (CLOP)	Proposed registered functions: the entity that owns and maintains, and the entity that operates, a Computational Load Site. Approved by NERC's Board in October 2026; pending FERC approval.
Contingency	The unexpected failure or outage of a system component, such as a generator, transmission line, circuit breaker, switch or other electrical element. (NERC Glossary)
Deliverability	As used in this reference, the ability of the transmission system to move power from generation resources to load during both normal and stressed conditions. Not a NERC Glossary term.
Interconnection	A geographic area in which the operation of Bulk Power System components is synchronized such that the failure of one or more components may adversely affect the ability of operators of other components to maintain Reliable Operation. When capitalized, one of the four major electric system networks in North America: Eastern, Western, ERCOT and Quebec. (NERC Glossary, summarized)
Large load	NERC Large Loads Task Force working definition: any commercial or industrial individual load facility or aggregation of load facilities at a single site behind one or more points of interconnection that can pose reliability risks to the BPS due to its demand, operational characteristics, or other factors. Not a NERC Glossary term.

Term	Meaning in this paper
Load	An end-use device or customer that receives power from the electric system. (NERC Glossary)
Planning Coordinator (PC)	Same as Planning Authority: the responsible entity that coordinates and integrates transmission Facilities and service plans, resource plans, and Protection Systems. (NERC Glossary)
Reliability Coordinator (RC)	The entity that is the highest level of authority who is responsible for the Reliable Operation of the Bulk Electric System, has the Wide Area view of the Bulk Electric System, and has the operating tools, processes and procedures, including the authority to prevent or mitigate emergency operating situations in both next-day analysis and real-time operations. (NERC Glossary, first sentence)
Reliable Operation	Operating the elements of the Bulk-Power System within equipment and electric system thermal, voltage, and stability limits so that instability, uncontrolled separation, or cascading failures of such system will not occur as a result of a sudden disturbance, including a cybersecurity incident, or unanticipated failure of system elements. (NERC Glossary)
Transmission Operator (TOP)	The entity responsible for the reliability of its "local" transmission system, and that operates or directs the operations of the transmission Facilities. (NERC Glossary)
Transmission Planner (TP)	The entity that develops a long-term (generally one year and beyond) plan for the reliability (adequacy) of the interconnected bulk electric transmission systems within its portion of the Planning Authority area. (NERC Glossary)

This glossary includes selected definitions from the NERC Glossary of Terms Used in NERC Reliability Standards as a convenience to readers. It does not supersede or modify the official NERC definitions.

How Energy Compliance Can Help

Registration and applicability analysis

If you own or operate a data center, crypto-mining site, or other computational load of 50 MW or more at 100 kV or above, the proposed Computational Load Owner and Computational Load Operator criteria may reach you. CLO-001-1 would add obligations for Transmission Planners, Planning Coordinators, and Transmission Owners, and CLO-003-1 would add obligations for Transmission Owners, once approved. EC's registration and applicability analysis tells you which functions and requirements apply, and when.

Program design for the CLO standards

EC provides compliance program design and improvement, operational and engineering reliability alignment, and mitigation planning and Self-Report development, so the data request list, the revised qualified change definition, the commissioning process, and the operator communications are in place and documented before the standards take effect.

Senior advisory and briefings

EC offers NERC reliability and compliance advisory support, senior advisory on complex reliability questions, reliability governance and program assessments, regulator-perspective program reviews, and training and executive briefings on reliability frameworks, including a board-level briefing on what the computational load framework means for your organization. EC also supports industry engagement in standards development and working-group participation, NERC compliance program support, interpretation, and audit preparation, audit and enforcement support (non-advocacy), and audit defense with Notice of Penalty response and settlement posture.

WattOps Compliance

WattOps Compliance is EC's NERC compliance evidence platform (wattopscompliance.com). EC will run one standard at one facility through WattOps at no cost (CIP standards excluded).

RenewOps

RenewOps is EC's renewable operations monitoring and analytics platform, with a Data Center module.

If a large load is coming to your footprint, or you are the large load, call before the interconnection agreement is signed.

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About the Author

Rob Smith is the Founder and Principal of Energy Compliance, Inc., with more than thirty years in the industry on every side of the system. He began in control-room operations as a Reliability Coordinator, Transmission Operator, and Power System Operator across RTO/ISO and utility control centers. On the regulator side, he was a senior compliance auditor and subject matter expert for NERC Reliability Standards. He audited grid facilities, evaluated mitigation adequacy, participated in risk-based oversight of utility mitigation activities, and supported the development of violation notifications and settlements in FERC-directed enforcement actions. He conducted a regulatory audit in the Sultanate of Oman against the Sultanate's Sector Law and Grid Code.

He founded Energy Compliance, Inc. to deliver senior regulator-side compliance authority without the layered staffing and billable-hour overhead of larger firms.

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- MBA, Energy Management, University of Mary
- MSL, Compliance Law, Fordham Law University
- BAS, Energy Management, Bismarck State College
- BAS, Mechanical Engineering, Metallurgy minor, University of Florida
- BAS, Criminology, St. Petersburg College (State Law Enforcement Certification)
- AAS, Power Plant Technology, Bismarck State College
- AAS, Electrical Transmission System Technology, Bismarck State College

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About Energy Compliance, Inc.

Energy Compliance, Inc. is an independent consulting and advisory firm based in Bloomington, Minnesota, focused exclusively on electric reliability, cybersecurity reliability, and regulatory compliance for organizations connected to the North American Bulk Electric System.

We support registered entities, including Generator Owners and Operators, Transmission Owners and Operators, Reliability Coordinators, Balancing Authorities, and Distribution Providers. Our work spans NERC Reliability Standards, FERC orders, RTO/ISO market participation rules, Regional Entity oversight, and state regulatory frameworks.

We do this work differently than larger consulting firms. A senior practitioner with regulator-side experience oversees every engagement. We staff for outcomes, not billable hours. Our deliverables are written to be operationally executable and audit-defensible, structured for the auditor's question rather than the consultant's binder. Where automation can replace manual work, we build the automation. Where senior judgment is required, the senior is in the room.

Energy Compliance is not affiliated with, sponsored by, or endorsed by the North American Electric Reliability Corporation, the Federal Energy Regulatory Commission, or any Regional Entity.

Learn more at energycomplianceinc.com.

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