TRACK 1: ENERGY POLICY

ReliabilityFirst Fall Reliability & Security Summit

September 16, 2026

RELIABILITY FIRST

Preparing for Load Growth: Insights from the Large Load Working Group (LLWG)

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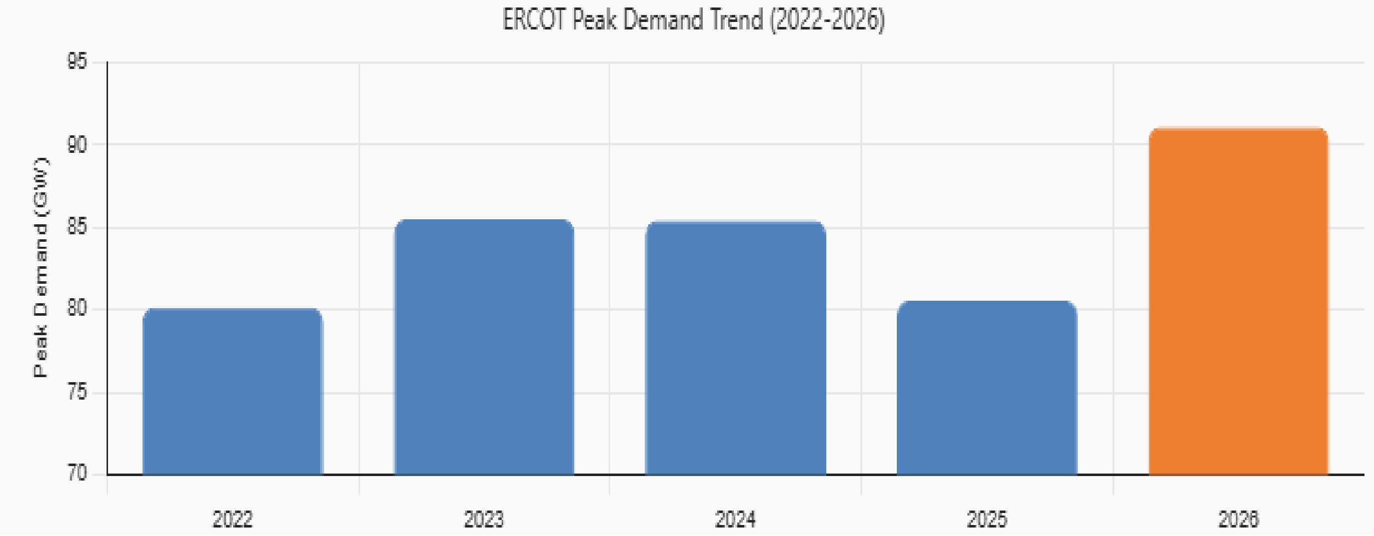
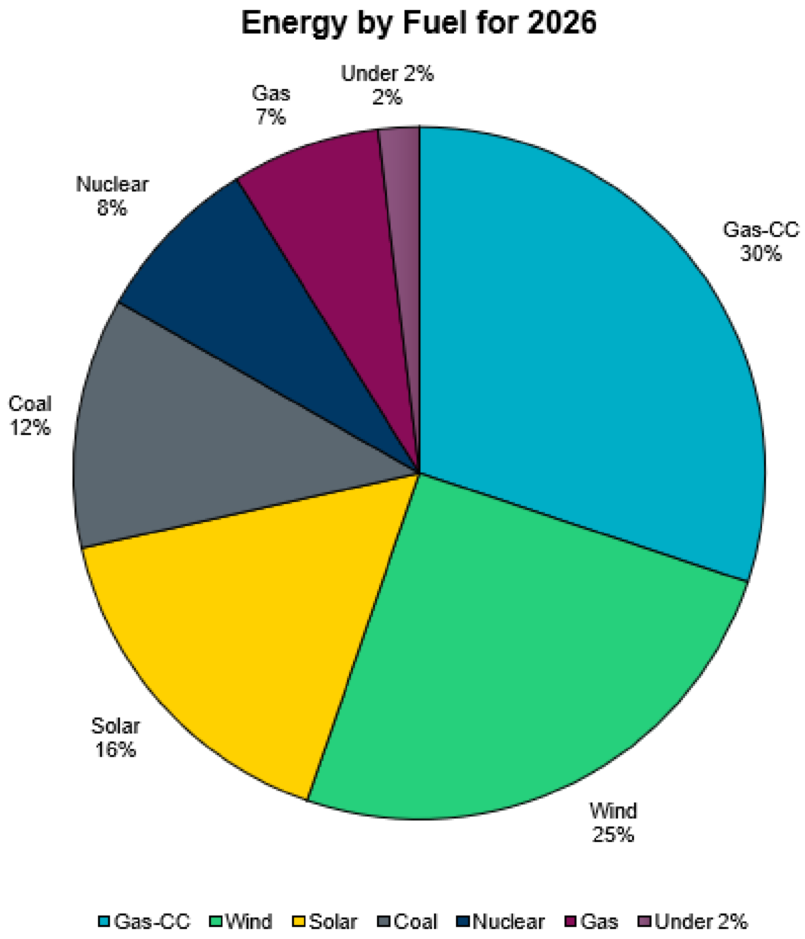
AMERICAN ELECTRIC POWER®

Preparing for load growth: Insights from the Large Load Working Group

The ERCOT Large Load Experience

ERCOT Demand & Resource Mix



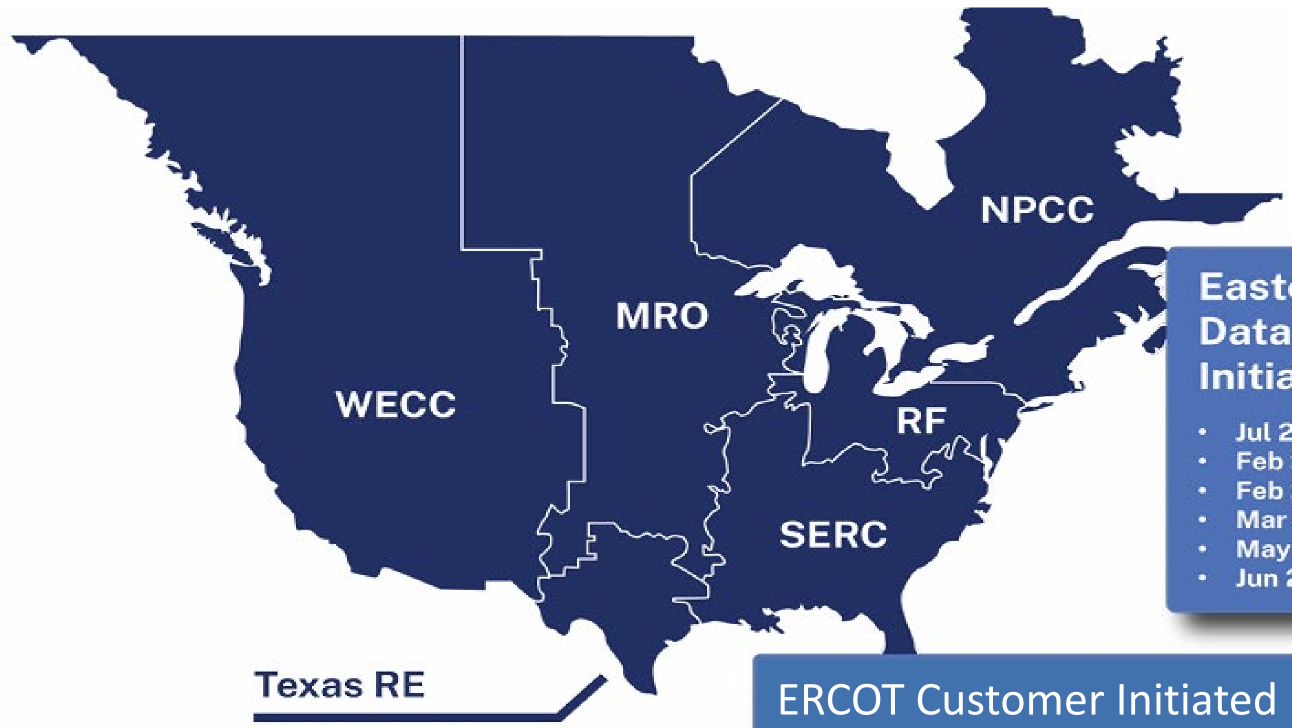


ERCOT as compared to Eastern Interconnect:

- Lower inertia per MW of load
- Rate of Change of Frequency (RoCoF) is much higher
- Lower system strength in many areas due to IBR concentration and fewer network connections

Greater sensitivity to Large Electronic Loads !

Customer Initiated Load Reduction Events



Eastern Interconnection Data Center Customer Initiated Load Reductions

- **Jul 2024:** 1,500 MW
- **Feb 2025:** 1,800 MW
- **Feb 2025:** 428 MW
- **Mar 2025:** 227 MW
- **May 2025:** 540 MW
- **Jun 2025:** 1,300 MW

ERCOT Customer Initiated Load Reductions

- Jan 2023 – April 2026
  - 28 Loss Events (100-450 MW)

<u>July 22, 2026 Event</u>

Normally cleared fault in Dominion resulted in approximately 3.8GW of data center load reduction

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ERCOT Large Load Queue

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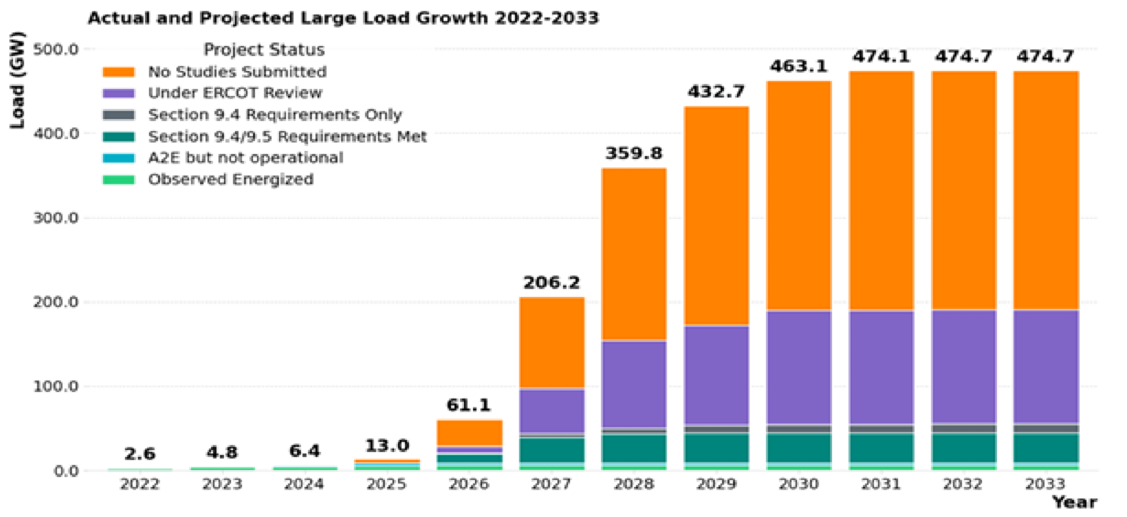
Large Load Interconnection Requests (as of June 2026)

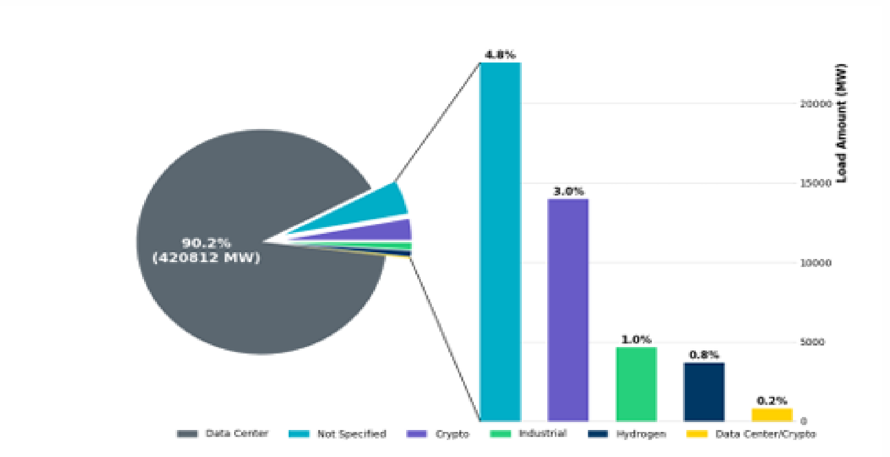
Actual and Projected Large Loads Growth 2022-2033



Project Status	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
No Studies Submitted	0.0	0.0	0.0	4.1	32.8	109.0	205.8	261.0	273.5	284.0	284.3	284.3
Under ERCOT Review	0.0	0.0	0.0	0.0	7.5	53.5	103.6	118.5	135.1	135.5	135.5	135.5
Section 9.4 Requirements Only	0.0	0.0	0.0	0.0	1.5	4.7	6.3	8.5	9.9	9.9	9.9	9.9
Section 9.4/9.5 Requirements Met	0.0	0.0	0.0	0.0	10.2	29.9	35.0	35.7	35.7	35.7	36.0	36.0
A2E but not operational	0.0	0.3	1.4	3.0	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Observed Energized	2.6	4.5	5.0	5.8	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Total (GW)	**2.6**	**4.8**	**6.4**	**13.0**	**61.1**	**206.2**	**359.8**	**432.7**	**463.1**	**474.1**	**474.7**	**474.7**

28 CILR Events with 4-6 GW of Large Loads

Large Loads by Project Type



Key Takeaway: ERCOT is tracking approximately 474 GW of Large Loads seeking interconnection, of which ~90% are data centers.

ERCOT Large Load Study Process

<u>“Interim” Large Load Process</u>

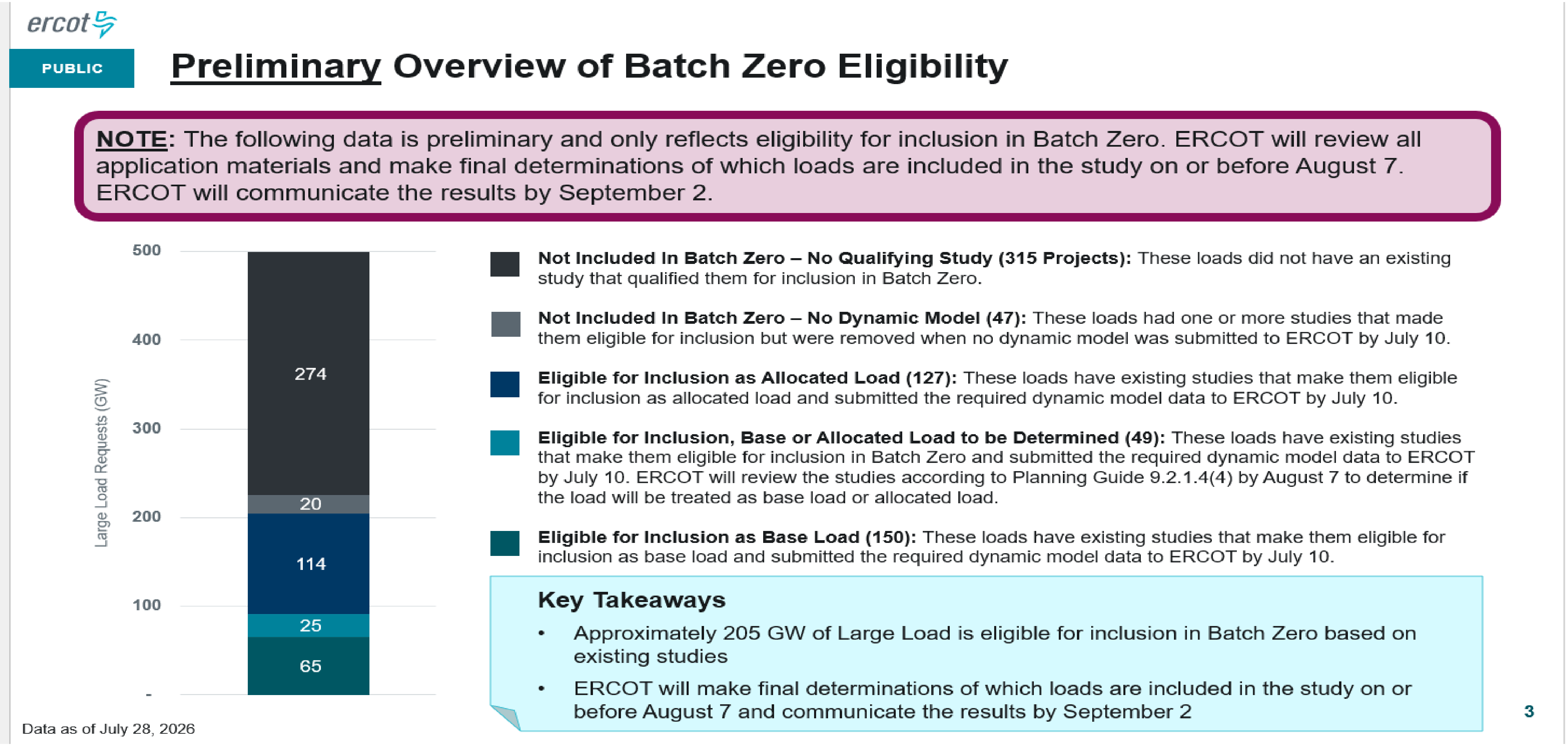
- Each large load request was studied separately
- Studies were primarily conducted by the host TSP
- ERCOT reviewed study results and determined whether additional analysis was needed
- New requests entering the same area often required existing studies to be restudied
- Transmission impacts were generally evaluated from a local or regional perspective rather than across the entire ERCOT system

<u>Batch Study Model</u>

- System-Wide Evaluation
- Rather than evaluating projects individually, ERCOT studies groups of requests together using common assumptions and planning cases
- Batch Zero serves as the transition mechanism from the legacy PGRR115 queue to the new process
  - Base Load
  - Studied Load
  - Excluded Load
  - Based on readiness, agreements, and study status

Volume and scale of large load requests require holistic approach

How Many Loads in Batch 0?



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Preliminary Overview of Batch Zero Eligibility

NOTE: The following data is preliminary and only reflects eligibility for inclusion in Batch Zero. ERCOT will review all application materials and make final determinations of which loads are included in the study on or before August 7. ERCOT will communicate the results by September 2.

■ **Not Included In Batch Zero – No Qualifying Study (315 Projects):** These loads did not have an existing study that qualified them for inclusion in Batch Zero.

■ **Not Included In Batch Zero – No Dynamic Model (47):** These loads had one or more studies that made them eligible for inclusion but were removed when no dynamic model was submitted to ERCOT by July 10.

■ **Eligible for Inclusion as Allocated Load (127):** These loads have existing studies that make them eligible for inclusion as allocated load and submitted the required dynamic model data to ERCOT by July 10.

■ **Eligible for Inclusion, Base or Allocated Load to be Determined (49):** These loads have existing studies that make them eligible for inclusion in Batch Zero and submitted the required dynamic model data to ERCOT by July 10. ERCOT will review the studies according to Planning Guide 9.2.1.4(4) by August 7 to determine if the load will be treated as base load or allocated load.

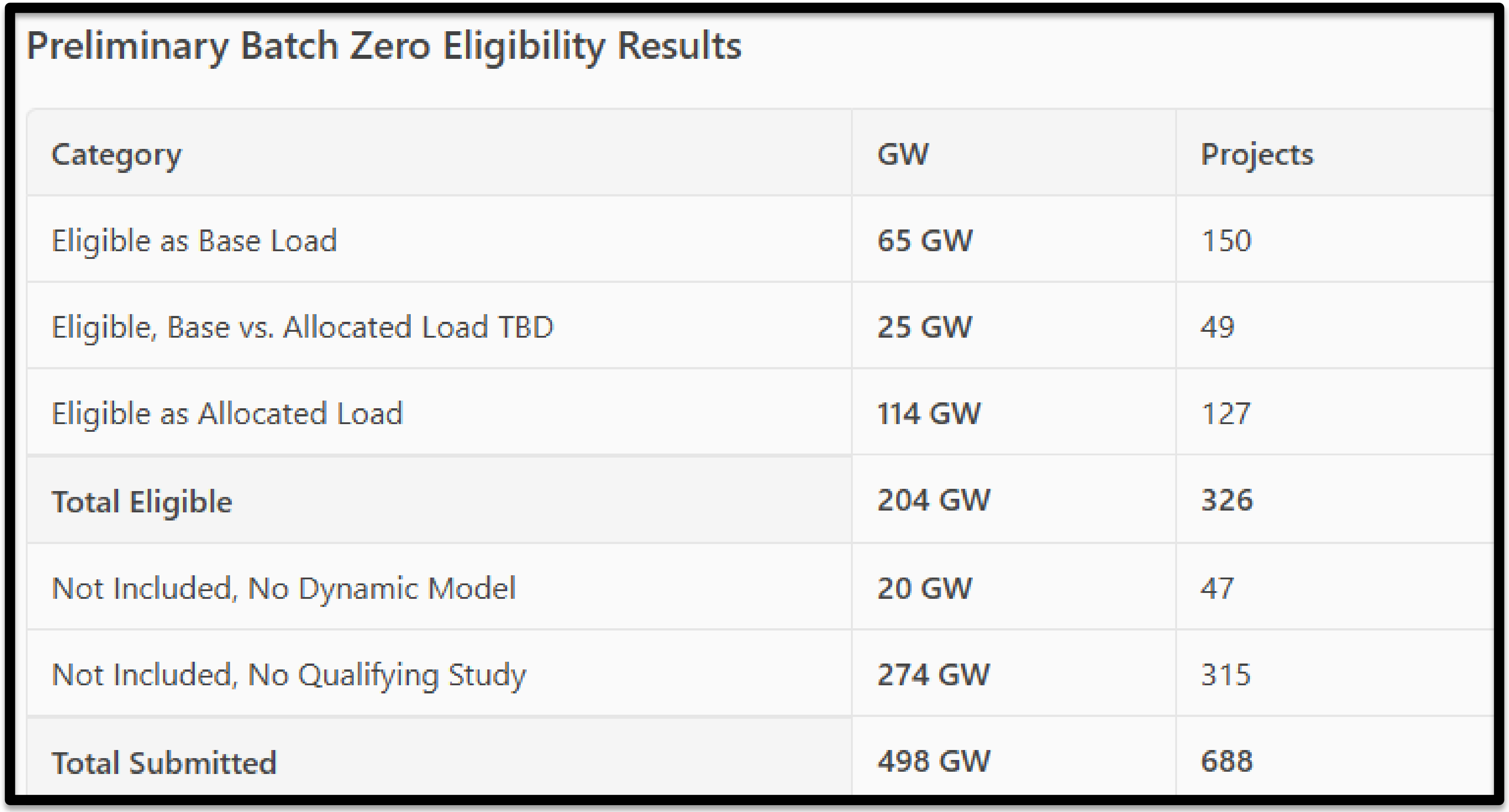
■ **Eligible for Inclusion as Base Load (150):** These loads have existing studies that make them eligible for inclusion as base load and submitted the required dynamic model data to ERCOT by July 10.

Key Takeaways

- Approximately 205 GW of Large Load is eligible for inclusion in Batch Zero based on existing studies
- ERCOT will make final determinations of which loads are included in the study on or before August 7 and communicate the results by September 2

Data as of July 28, 2026

ERCOT Batch Zero Composition



Preliminary Batch Zero Eligibility Results

Category	GW	Projects
Eligible as Base Load	65 GW	150
Eligible, Base vs. Allocated Load TBD	25 GW	49
Eligible as Allocated Load	114 GW	127
Total Eligible	**204 GW**	**326**
Not Included, No Dynamic Model	20 GW	47
Not Included, No Qualifying Study	274 GW	315
Total Submitted	**498 GW**	**688**

Batch Zero Status

- Original schedule targeted August for final Batch Zero qualification and April, 2027 for the Batch Zero Interconnection Study results.

August 3, 2026 Governor Abbott directive:

- Governor Abbott instructed the PUCT and ERCOT to conduct a "comprehensive verification and audit" of data centers advancing through ERCOT's large-load interconnection process before those projects could continue moving forward.

- Immediate Impact on Batch Zero
  - Upon receiving the directive, ERCOT:
    - Paused the Batch Zero study process.
    - Delayed the August 7 classification notices.
    - Suspended approvals to energize new large data centers and crypto facilities of 75 MW or greater.
    - Requested Good Cause Exceptions from the PUCT to modify the Batch Zero schedule.

BZ Eligibility and Community Impact Reviews

1. Batch Zero Eligibility Verification

ERCOT would confirm that every large load included in Batch Zero actually satisfied the applicable PGRR145 eligibility criteria. This included:

- Reviewing eligibility attestations.
- Requesting supporting documentation from TSPs and DSPs.
- Performing site-readiness verification for certain projects.
- Providing an opportunity to cure deficiencies.
- Disqualifying projects that failed verification or did not respond.

2. Community Impact Review

ERCOT would collect additional information from data center and crypto projects of 25 MW and larger regarding:

- Grid impacts
- Water usage
- Public financial assistance
- Ownership
- Community impacts
- On-site generation arrangements

Major Reliability Concerns with Large Computational Loads

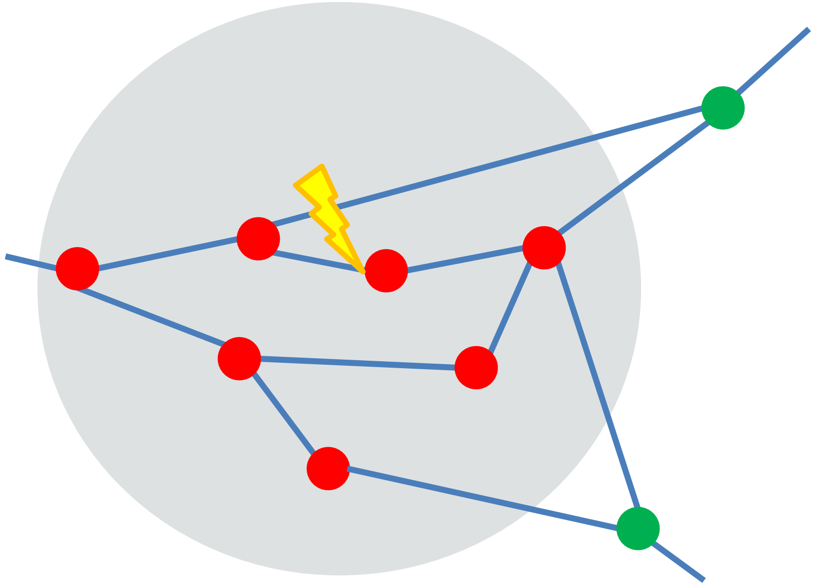
- Customer Initiated Load Reductions (CILR)
  - Voltage Ride-Through
  - Frequency Ride-Through
- Post-Fault Active Power Recovery (PFAPR)

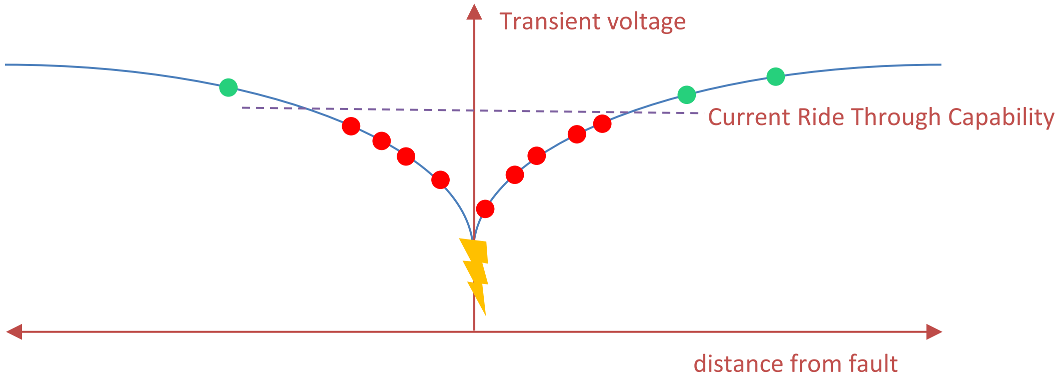
ERCOT Frequency Limit Study

MW Load Loss	Frequency Max
~3,400	60.43
~3,300	60.43
~3,200	60.38
~2,600	60.21

System frequency above 60.4Hz raises concern that generators may not ride-through which could lead to an uncontrolled cascading event

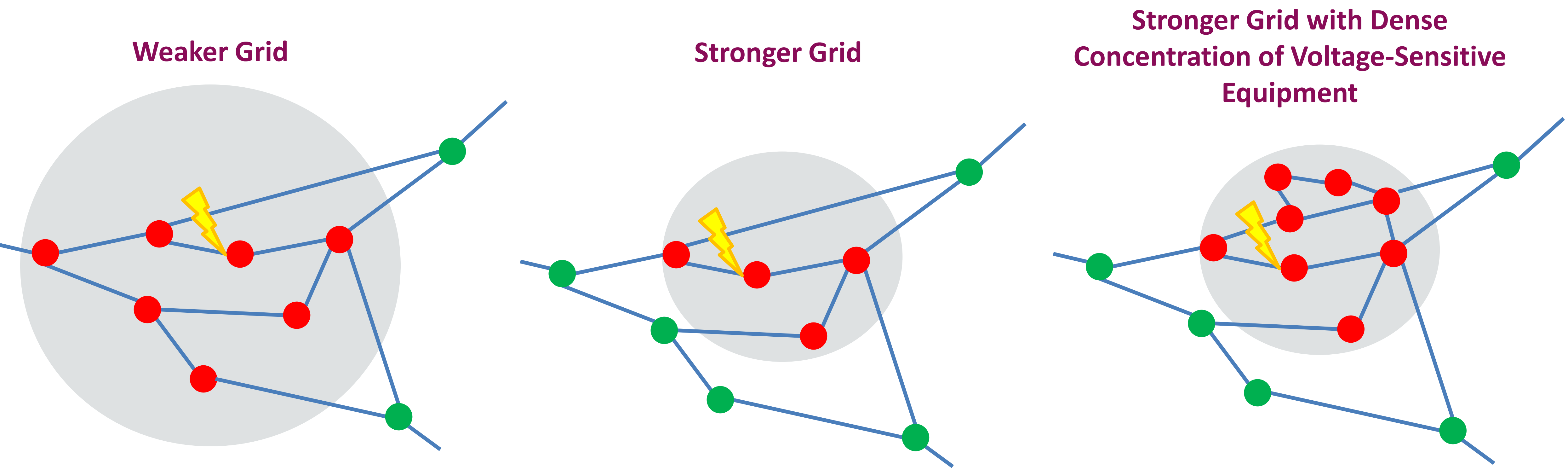
What is Voltage Ride-Through?





- ⚡ Location of the fault
- ● Area affected by voltage dip resulting from the fault
- 🟢 Equipment located outside the area of voltage dip
- 🔴 Equipment located inside the area of voltage dip (may trip if unable to ride-through)

Grid-Side Mitigations Can Help...



Strengthening the grid reduces the area affected by voltage dip during a fault

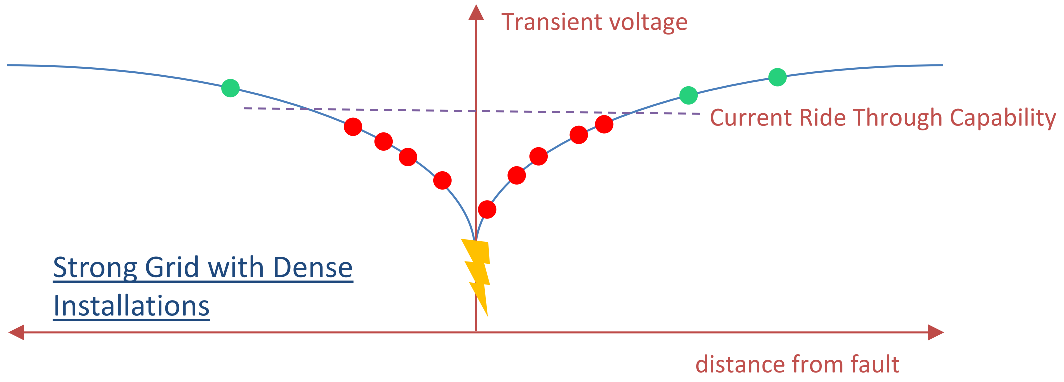
- New network connections, Statcom, E-Statcom, etc

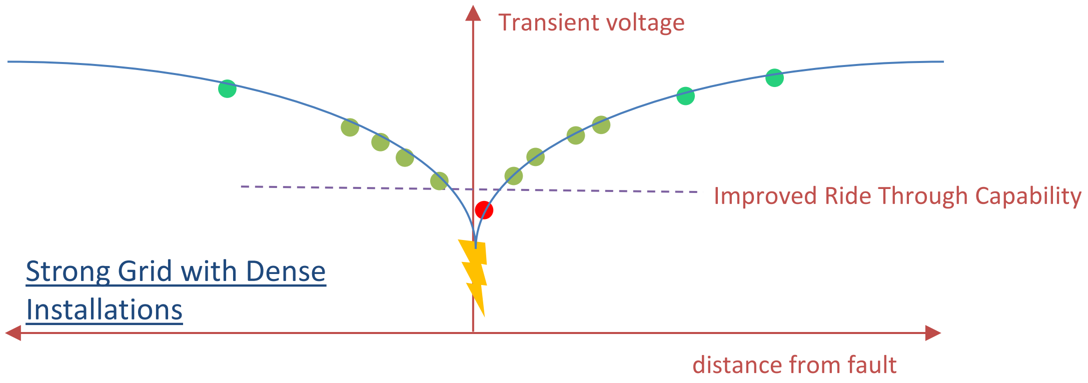
The area affected by the voltage dip is the same size, but there is more equipment concentrated in that area

⚡ Location of the fault
● Area affected by voltage dip resulting from the fault
🟢 Equipment located outside the area of voltage dip
🔴 Equipment located inside the area of voltage dip (may trip if unable to ride-through)

BUT there may still be a problem

More Help is Needed





- If the amount of LELs affected by the voltage dip is too high, it may cause instability or cascading if it does not ride through
- Improvement of ride-through capability at each facility will reduce aggregate risk

Key Takeaway: Improved Ride-Through Capability is needed.

What is ERCOT Doing?

- ERCOT proposed NOGRR 282 and NPRR 1308
  - establish performance requirements for Large Electronic Loads (LELs), defined generally as large loads (>75 MW) where at least 50% of demand is computational load such as data centers and crypto-mining facilities
  - The requirements include:
    - Voltage ride-through (VRT)
    - Frequency ride-through (FRT)
    - Demonstration of compliance
    - Potential corrective actions for non-compliance
- Became effective August, 2026

NERC Activity on Computational Loads

What is NERC Doing?

- NERC established Large Load Task Force (LLTF), now Large Load Working Group (LLWG) in October 2024
  - Foundational Documents
    - Characteristics and risks white paper (July 2025)
    - Assessment of gaps in existing practices, requirements and reliability standards (March 2026)
      - SAR Roadmap
- Revisions to Rules of Procedure (ROP)
  - Registration for Computational Loads
    - Rules of Procedure (ROP) revisions out for comment (09-18-2026):
      - Create a new defined term: Computational Load Site (CLS)
      - Create new NERC registration categories:
        - » Computational Load Owner (CLO)
        - » Computational Load Operator (CLOP)
      - Establish registration criteria identifying which large computational loads become NERC registered entities.
      - Draft threshold is greater than or equal to 50MW connected to BPS at 100kV or above
- Initiated Project 2026-02 Computational Loads

Project 2026-02 Computational Loads

- Develops New Reliability Standards
  - CLO-001-1 Computational Load Interconnection, Studies, & Modeling Data
  - CLO-002-1 – Computational Load Operational Data and Communications
  - CLO-003-1 – Computational Load Protection Coordination & Disturbance Monitoring
- Modifies Existing Standards
  - FAC-001 (Interconnection Requirements)
  - FAC-002 (Interconnection Studies)
- Draw Heavily from Existing Standards

CLO-001-1

Computational Load Interconnection, Studies & Modeling Data (11 Requirements)

Purpose

- Establish reliability requirements for interconnection, study, commissioning, and modeling of large Computational Load Sites connected to the Bulk Power System.
- Ensure computational loads are accurately represented in planning assessments from project inception through operation.

Key Requirements

- Interconnection coordination and commissioning processes.
- Planning and reliability studies for new and modified computational loads.
- Identification and evaluation of qualified changes to existing sites.
- Provision, verification, and maintenance of model data.

Reliability Benefits

- Improves visibility into computational load characteristics before energization.
- Reduces planning uncertainty through standardized study and modeling requirements.
- Improves accuracy of reliability assessments and planning cases.
- Provides a consistent framework for evaluating large electronic load impacts across North America.

CLO-001 establishes the planning and modeling foundation necessary to reliably integrate large computational loads into the Bulk Power System.

CLO-002-1

Computational Load Operational Data & Communications (15 Requirements)

Purpose

- Ensure Reliability Coordinators, Balancing Authorities, and Transmission Operators have the operational data and communication capabilities needed to reliably manage large computational loads.

Key Requirements

- Provision of operational data needed for real-time reliability assessments.
- Establishment of interpersonal communications between computational load operators and grid operators.
- Communication protocols for receiving and responding to Operating Instructions.
- Procedures supporting prompt reliability actions during abnormal system conditions.

Reliability Benefits

- Improves operator situational awareness of large computational loads.
- Enables timely coordination between load operators and grid operators.
- Supports effective response to reliability events and operating instructions.
- Enhances operational visibility during load ramping, curtailments, and reconnection events.

CLO-002 provides the operational visibility and communication pathways needed to manage large computational loads in real time

CLO-003-1

Computational Load Protection Coordination & Disturbance Monitoring (10 Requirements)

Purpose
- Establish protection coordination and disturbance monitoring requirements for Computational Load Sites.

Key Requirements
- Coordinate protection systems between computational loads and the interconnected grid.
- Install and maintain disturbance monitoring equipment.
- Capture high-resolution event data for post-event analysis.

Reliability Benefits
- Reduces the risk of unnecessary or widespread load trips caused by protection miscoordination.
- Improves understanding of computational load behavior during disturbances.
- Provides high-resolution event data to support root-cause analysis and corrective actions.
- Supports model validation and continuous reliability improvements.

CLO-003 creates the monitoring and protection framework needed to understand, analyze, and mitigate reliability impacts from large computational load disturbances.

Proposed Implementation Plan

CLO-001	Applicability	Requirements	Implementation
Interconnection Process & Requirements	TO, DP, GO	R1, R2, R3	Reg Approval → Next Quarter → +6 Months
Qualified Change & Modeling Data Specifications	TP, PC	R7, R8	Reg Approval → Next Quarter → +3 Months
Study Coordination	TP, PC, TO, DP, GO, CLO	R4, R5, R6	Reg Approval → Next Quarter → +9 Months
Provision of Modeling Data & Data Verification	CLO	R9, R10, R11	Reg Approval → Next Quarter → +9 Months

CLO-002	Applicability	Requirements	Implementation
Operational Data Specifications	RC, BA, TOP	R1, R2, R3, R4, R5, R6	Reg Approval → Next Quarter → +6 Months
Provision of Operational Data	CLO, CLOP	R7	Reg Approval → Next Quarter → +12 Months
Adherence to Operating Instructions*	CLOP	R8, R9	Reg Approval → Next Quarter → +12 Months
Interpersonal Communications*	TOP, BA, CLOP	R10, R11, R12, R13	Reg Approval → Next Quarter → +12 Months
Oral Communication Protocol & Training*	CLOP	R14, R15	Reg Approval → Next Quarter → +12 Months

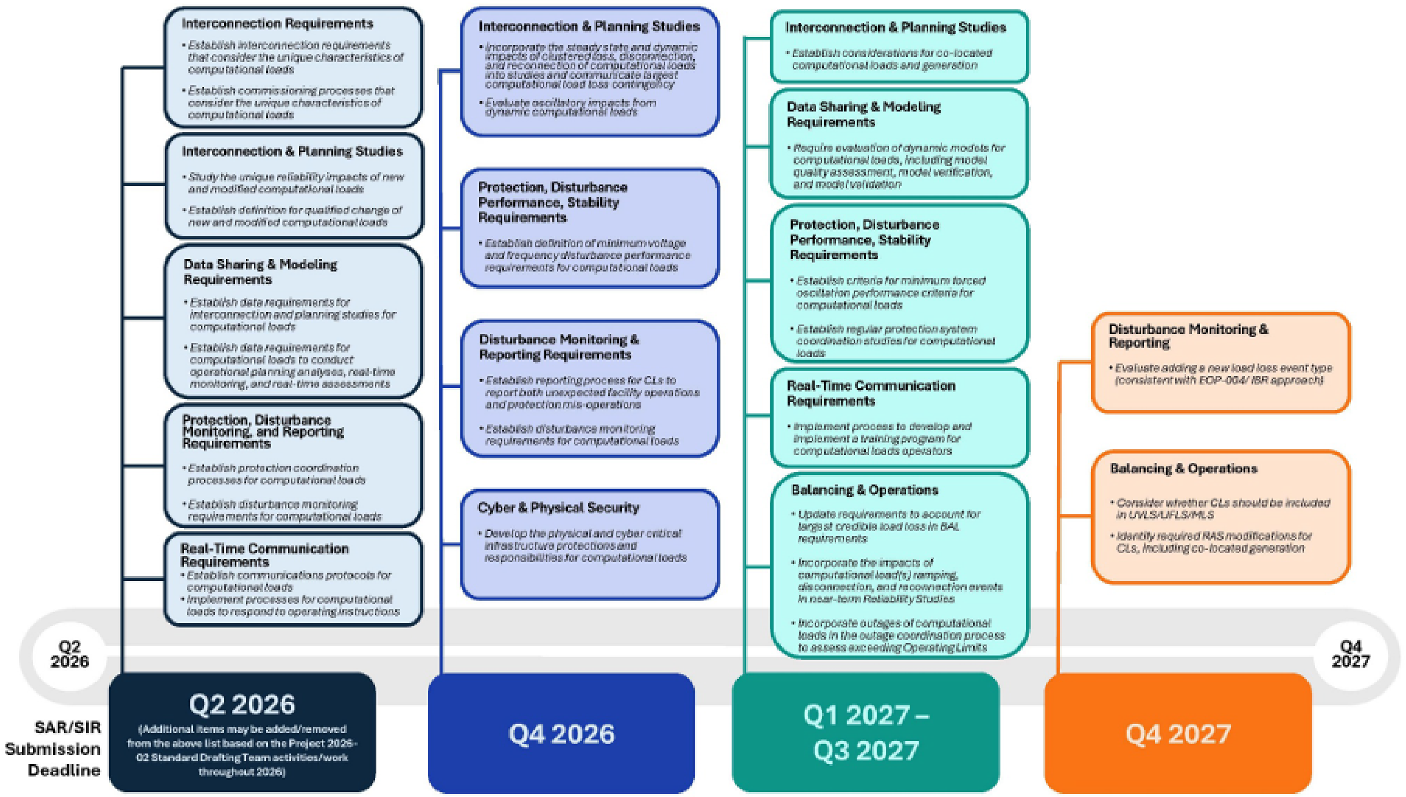
*Deadline extension possible under certain circumstances for R8-R15

CLO-003	Applicability	Requirements	Implementation
Protection Coordination	CLO	R9, R10	Reg Approval → Next Quarter → +9 Months
SER, FR, and DDR Monitoring Equipment**	CLO, TO, GO, DP	R1* – R8	Reg Approval → Next Quarter (Effective Date) Sites In-Service *Prior to* Effective Date → +36 Months Sites In-Service *After* Effective Date → +15 Months

*SER data in R1 is only applicable to CLO

** Deadline extension possible under certain circumstances for R1-R8

NERC LLWG SAR Roadmap



Q2 2026

Interconnection Requirements
- *Establish interconnection requirements that consider the unique characteristics of computational loads*
- *Establish commissioning processes that consider the unique characteristics of computational loads*

Interconnection & Planning Studies
- *Study the unique reliability impacts of new and modified computational loads*
- *Establish definition for qualified change of new and modified computational loads*

Data Sharing & Modeling Requirements
- *Establish data requirements for interconnection and planning studies for computational loads*
- *Establish data requirements for computational loads to conduct operational planning analyses, real-time monitoring, and real-time assessments*

Protection, Disturbance Monitoring, and Reporting Requirements
- *Establish protection coordination processes for computational loads*
- *Establish disturbance monitoring requirements for computational loads*

Real-Time Communication Requirements
- *Establish communications protocols for computational loads*
- *Implement processes for computational loads to respond to operating instructions*

Q4 2026

Interconnection & Planning Studies
- *Incorporate the steady state and dynamic impacts of clustered loss, disconnection, and reconnection of computational loads into studies and communicate largest computational load loss contingency*
- *Evaluate oscillatory impacts from dynamic computational loads*

Protection, Disturbance Performance, Stability Requirements
- *Establish definition of minimum voltage and frequency disturbance performance requirements for computational loads*

Disturbance Monitoring & Reporting Requirements
- *Establish reporting process for CLs to report both unexpected facility operations and protection mis-operations*
- *Establish disturbance monitoring requirements for computational loads*

Cyber & Physical Security
- *Develop the physical and cyber critical infrastructure protections and responsibilities for computational loads*

Q1 2027 – Q3 2027

Interconnection & Planning Studies
- *Establish considerations for co-located computational loads and generation*

Data Sharing & Modeling Requirements
- *Require evaluation of dynamic models for computational loads, including model quality assessment, model verification, and model validation*

Protection, Disturbance Performance, Stability Requirements
- *Establish criteria for minimum forced oscillation performance criteria for computational loads*
- *Establish regular protection system coordination studies for computational loads*

Real-Time Communication Requirements
- *Implement process to develop and implement a training program for computational loads operators*

Balancing & Operations
- *Update requirements to account for largest credible load loss in BAL requirements*
- *Incorporate the impacts of computational load(s) ramping, disconnection, and reconnection events in near-term Reliability Studies*
- *Incorporate outages of computational loads in the outage coordination process to assess exceeding Operating Limits*

Q4 2027

Disturbance Monitoring & Reporting
- *Evaluate adding a new load loss event type (consistent with EOP-004/ IBR approach)*

Balancing & Operations
- *Consider whether CLs should be included in UVLS/UFLS/MLS*
- *Identify required RAS modifications for CLs, including co-located generation*

SAR/SIR Submission Deadline

Q2 2026 (Additional items may be added/removed from the above list based on the Project 2026-02 Standard Drafting Team activities/work throughout 2026)

Figure 1: SAR/SIR Development Roadmap[3]

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[3] The timeline shown reflects SAR development (the proposal for a standard project), not the standard project development process (the process that develops and formalizes regulations).

Computational Loads Standard Authorization Request Roadmap | July 2026

NERC LLWG Near-Term Actions

- DRAFT White Paper: Large Load Disturbance Performance: Impact Analysis and Ride-Through Recommendations

- Draft SAR: Disturbance Performance Requirements for Computational Loads (comment period)
  - Establish explicit disturbance ride-through expectations
  - Address Customer-Initiated Load Reduction (CILR) events
  - Define performance expectations during voltage and frequency disturbances

- White Paper in Progress: Simulation and Study Considerations for Large Loads
  - Describe when positive sequence phasor domain dynamic studies are necessary and when EMT modeling and studies are required
  - Identify the types of studies (e.g. SSO, control interactions, torsional studies, etc.) applicable to each study method

- Added to LLWG Work Plan
  - SAR: Studying Computational Load Loss in Planning and Near-Term Reliability Studies
  - SAR: Computational Load Event Reporting, Model Validation, and Quality Assessment

FORWARD TOGETHER RELIABILITYFIRST

SESSION BREAK

Energy Assurance: Strengthening Preparedness Across the Electricity Sector

Tim Fryfogle

Principal Engineer - Resources, Engineering, & System Performance, ReliabilityFirst

RELIABILITY FIRST

AGENDA

ELECTRIC GRID OVERVIEW

RESOURCE ADEQUACY

ENERGY ASSESSMENTS

SOLUTIONS FOR CONSIDERATION

FORWARD TOGETHER RELIABILITYFIRST

THE ELECTRIC GRID

From Power Generation to End Users

1. GENERATION

Electricity is produced at power plants.

2. TRANSMISSION

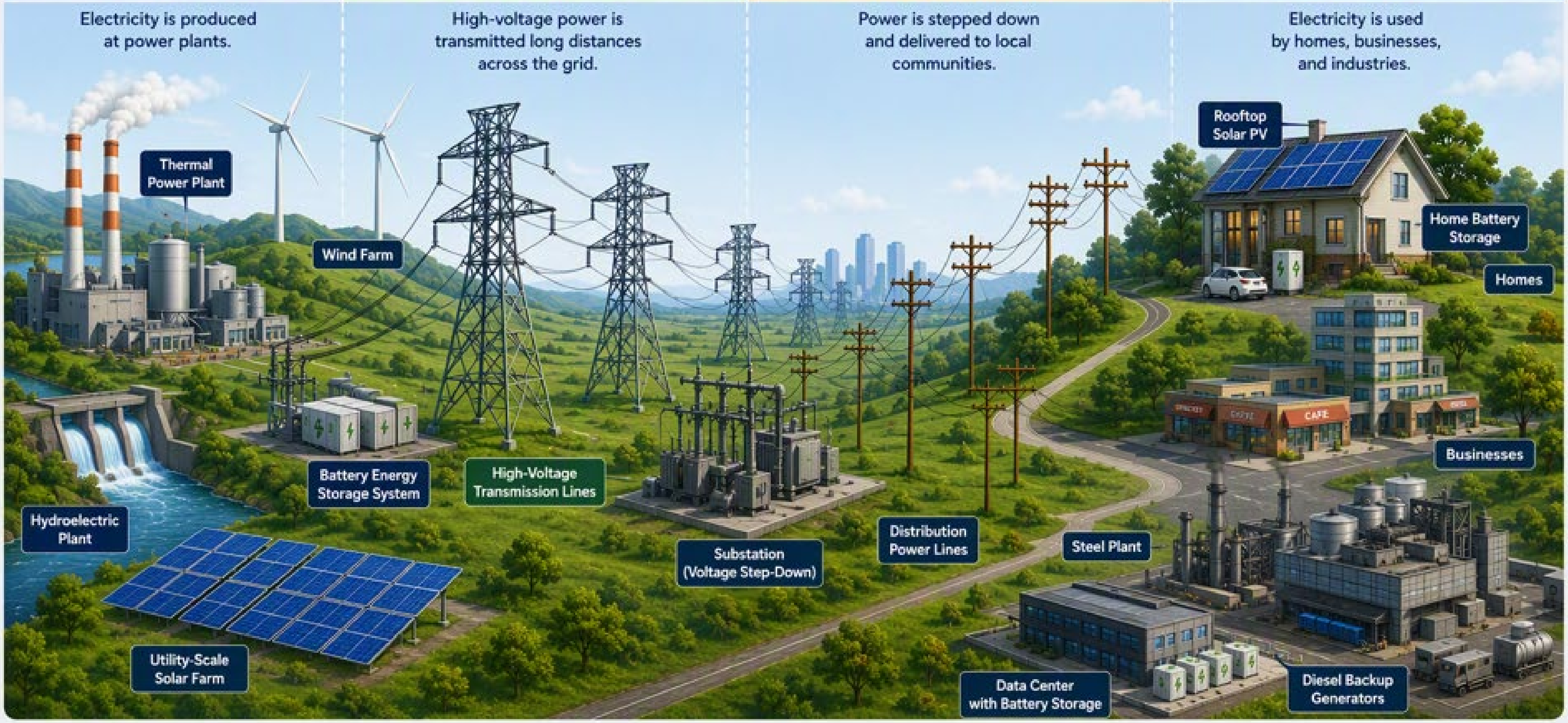
High-voltage power is transmitted long distances across the grid.

3. DISTRIBUTION

Power is stepped down and delivered to local communities.

4. END USERS

Electricity is used by homes, businesses, and industries.



Reliable
Delivering power when it's needed.

Resilient
Withstanding storms, faults, and disruptions.

Efficient
Operating the grid safely and economically.

Sustainable
Integrating clean energy for the future.

SERVING GROWING DEMAND

Proper modeling and planning are critical to enabling regional economic growth

Computational load impacts

Data centers, manufacturing, and electrification can concentrate demand in locations where the grid was not originally designed for that scale.

Why it matters

Reliability risk can constrain economic development if infrastructure cannot keep pace with demand growth.

MAKING GENERATION DELIVERABLE

The question is not just “how much supply?” – but also, "can it **serve** load?”

Generation location matters

New resources may be far from the customers or load centers they are intended to serve.

Constraints matter

A bottleneck can limit deliverability even when enough generation exists in the region. It can also restrict dispatch of lower cost resources.

Timing matters

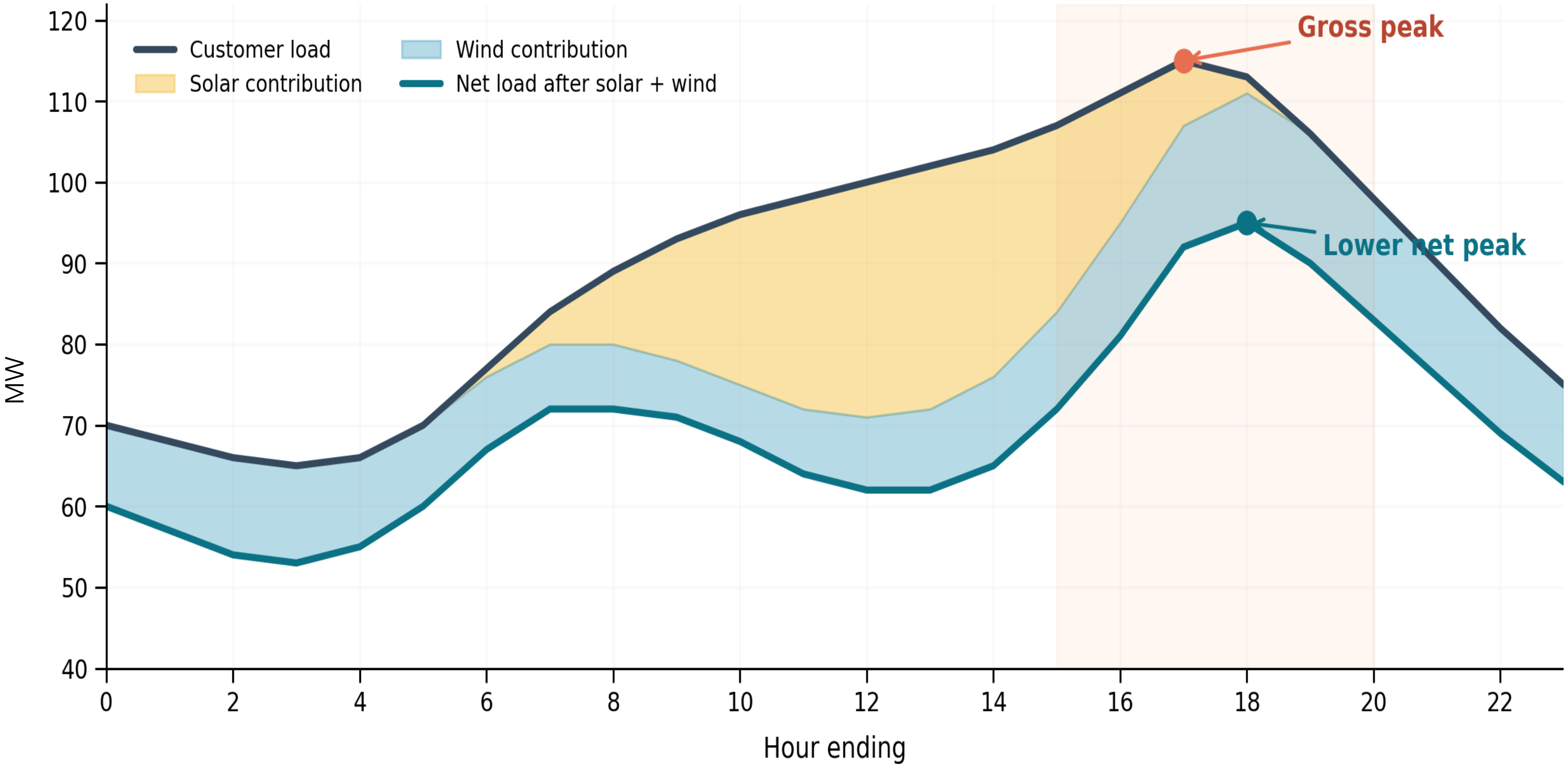
Generation additions and transmission reinforcements may not move on the same schedule.

Deliverability impacts operational limitation, cost to connect, interconnection timing, and local reliability.

TYPICAL PEAK LOAD DAY: SOLAR AND WIND BENEFITS

Variable generation reduces net load, but the timing of output determines the contribution during the peak-risk window

Illustrative Typical Summer Peak Day



KEY BENEFITS

- **Solar lowers daytime load**

  Strong midday production reduces the load served by other resources.

- **Wind broadens coverage**

  Output can contribute across daytime and evening hours.

- **Combined output lowers net peak**

  Solar and wind together reduce the height of the remaining net-load peak.

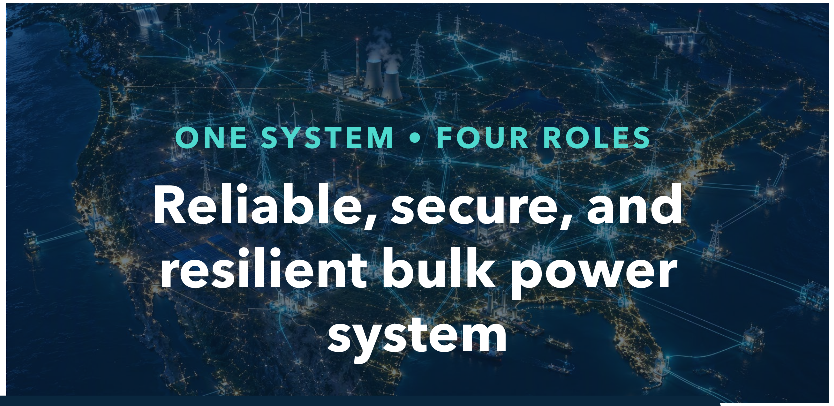
- **Timing still matters**

  Solar output declines toward evening, so wind and other flexible resources remain important.

Illustrative normalized profiles, not actual system data

NERC'S SUBJECT MATTER EXPERTS

Governance, technical review and wide-area modeling combine to produce actionable bulk power system reliability insight.



ONE SYSTEM • FOUR ROLES

Reliable, secure, and resilient bulk power system

NERC North American Electric Reliability Corporation

Sets and enforces reliability standards and assesses reliability of the North American bulk power system.

RAS **Reliability Assessment Subcommittee**

ASSESSMENT OVERSIGHT

Reviews and reports on bulk power system adequacy and security, including NERC seasonal and 10-year forward assessments and data collections.

→

PAWG **Probabilistic Assessment Working Group**

PROBABILISTIC METHODS

Advances probabilistic Monte-Carlo resource adequacy analysis and supports core and special probabilistic studies.

→

WAEA **Wide Area Energy Assessment**

WIDE-AREA APPLICATION

Combines interconnection models, common scenarios and transfer interactions to reveal interconnection-wide energy risk.

IN PRACTICE

NERC provides the mandate; RAS guides the assessment review; PAWG deepens the probabilistic analysis; WAEA applies them across a wider geographic footprint.

RELIABILITY ASSESSMENTS

NERC PUBLICATION CADENCE

JAN **Long-Term Reliability Assessment**

2026 LTRA: January 2027

MAY **Summer Reliability Assessment**

2026 SRA: May 2026

NOV **Winter Reliability Assessment**

2026–2027 WRA: November 2026

10-YEAR OUTLOOK

Annual view of bulk power system adequacy, security, and reliability over a 10-year horizon.

JUNE–SEPTEMBER

Electricity supply adequacy for the upcoming summer peak demand period.

DECEMBER–FEBRUARY

Electricity supply adequacy for the upcoming winter peak demand period.

Special Reliability Assessments: published as conditions warrant or when requested, rather than on a fixed annual date.

RF REGIONAL RESOURCES

SUMMER SEASONAL READINESS

Summer Newsletter Article

Near-term summer resource adequacy outlook using PJM and MISO data to assess expected and stressed demand conditions.

WINTER SEASONAL READINESS

Winter Newsletter Article

Cold-weather view of resource availability and outage risk, focused on the ability to serve forecast winter demand.

10-YEAR LONG-TERM OUTLOOK

Resource Adequacy Report

Forward-looking assessment of demand growth, resource changes, infrastructure timing, and potential reliability shortfalls.

RRA REGIONAL PRIORITIES

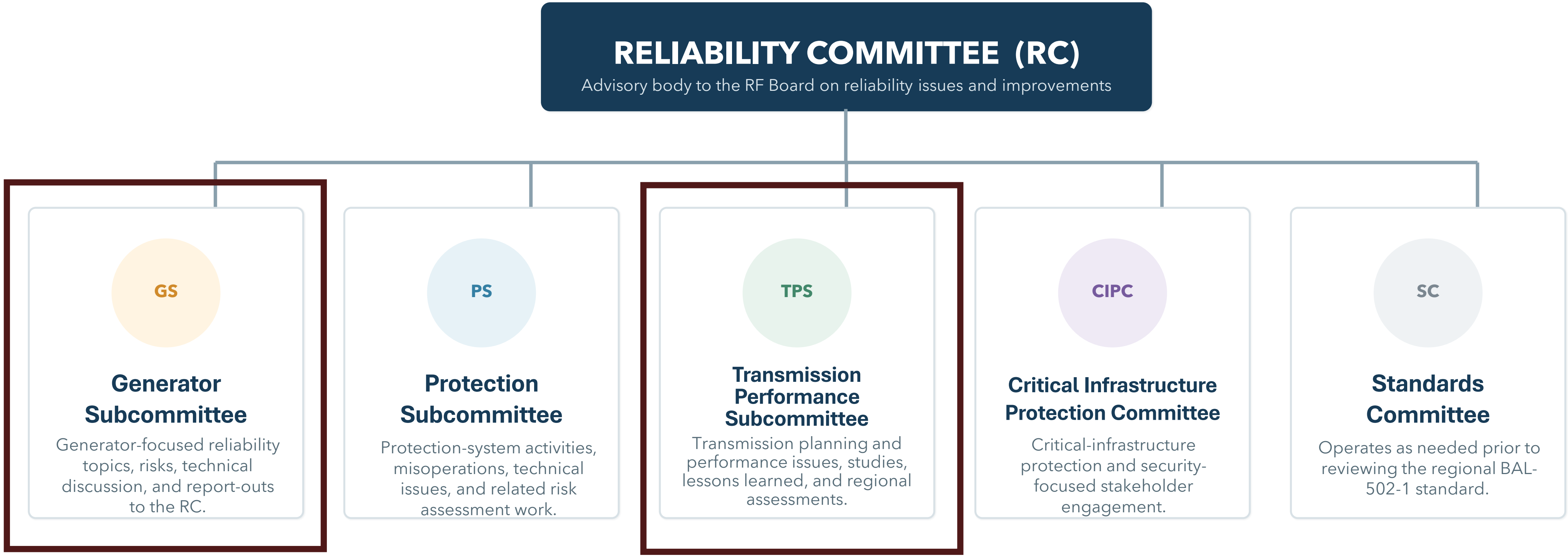
Regional Risk Assessment

Regional perspective on significant reliability risks, informed by stakeholder input, performance data, and trend analysis.

ONE STORY, THREE HORIZONS • Seasonal readiness • Long-term resource sufficiency • Regional risk priorities

RF COMMITTEES AND SUBCOMMITTEES

Stakeholder advisory and technical groups connect regional reliability priorities with focused subject-matter work.



RELIABILITY COMMITTEE (RC)

Advisory body to the RF Board on reliability issues and improvements

GS

Generator Subcommittee

Generator-focused reliability topics, risks, technical discussion, and report-outs to the RC.

PS

Protection Subcommittee

Protection-system activities, misoperations, technical issues, and related risk assessment work.

TPS

Transmission Performance Subcommittee

Transmission planning and performance issues, studies, lessons learned, and regional assessments.

CIPC

Critical Infrastructure Protection Committee

Critical-infrastructure protection and security-focused stakeholder engagement.

SC

Standards Committee

Operates as needed prior to reviewing the regional BAL-502-1 standard.

STRUCTURE IN PRACTICE

Subcommittees develop technical insight and work products, then report activities and reliability concerns to the Reliability Committee.

ENERGY ASSURANCE STANDARDS

Three complementary views of reliability: near-term energy, long-term energy, and regional capacity adequacy

NEAR-TERM ENERGY

BAL-007-1

ACCOUNTABLE ENTITY	TIME HORIZON
Balancing Authority	**Near Term**

- Conduct and document Near-Term Energy Reliability Assessments
- Account for demand, resource limits and fuel, transfers, and known transmission constraints
- Develop and implement Operating Plans when forecast energy emergencies are identified

Question answered: Can the system supply enough energy in the near term?

LONG-TERM ENERGY

Project 2024-02 (ERA-001-1)

Long-Term ERA Standard (draft)

ACCOUNTABLE ENTITY	TIME HORIZON
Planning Coordinator	**Beyond year one**

- Perform hourly energy reliability assessments across long-term planning periods
- Model demand, variable resources, storage, fuel availability, outages, transfers, and transmission limits
- Define unacceptable risk criteria and mitigate identified energy risks

Question answered: Will the future resource mix deliver enough energy across time?

REGIONAL CAPACITY

BAL-502-RF-03

RF regional standard

ACCOUNTABLE ENTITY	TIME HORIZON
Planning Coordinator	**Long-term planning**

- Perform and document an annual resource adequacy analysis
- Establish a planning reserve margin using the one-day-in-ten-years LOLE principle
- Document projected load and resource capability for areas and constrained sub-areas

Question answered: Is sufficient dependable capacity planned for the RF region?

Together: BAL-502 establishes the regional capacity baseline; BAL-007-1 and Project 2024-02 add chronological energy-risk assessment across near-term and long-term horizons.

Resource Adequacy

Is there enough resource capacity to meet peak demand while experiencing resource unavailability?

NAMEPLATE, CAPACITY, & ENERGY

Installed generation tells only part of the reliability story. Resource adequacy focuses on resource capacity during the peak hour.

Generator nameplate

Designed megawatt output of the unit

Installed capacity

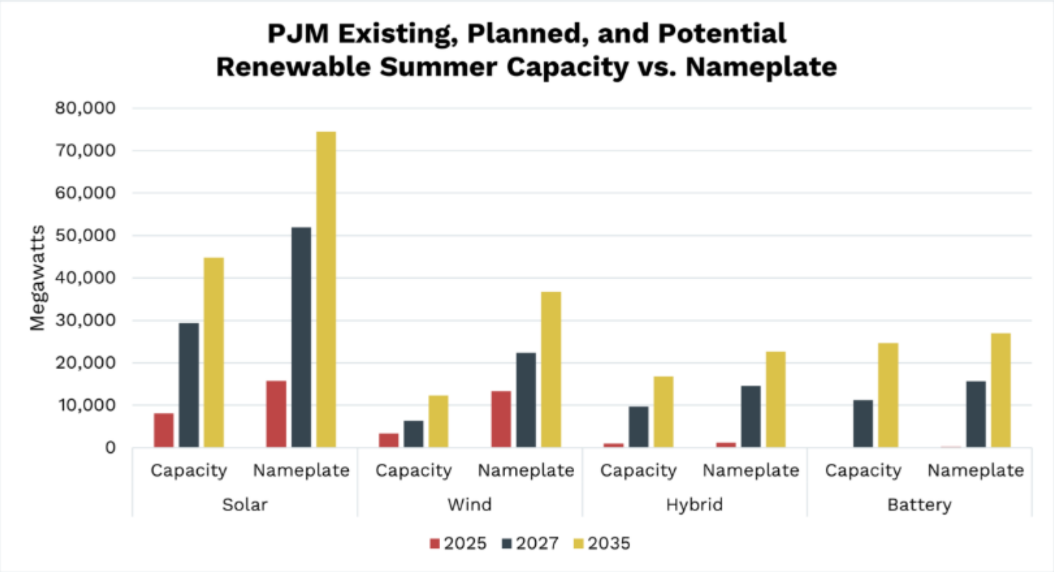
Megawatt output that can be produced at a defined moment

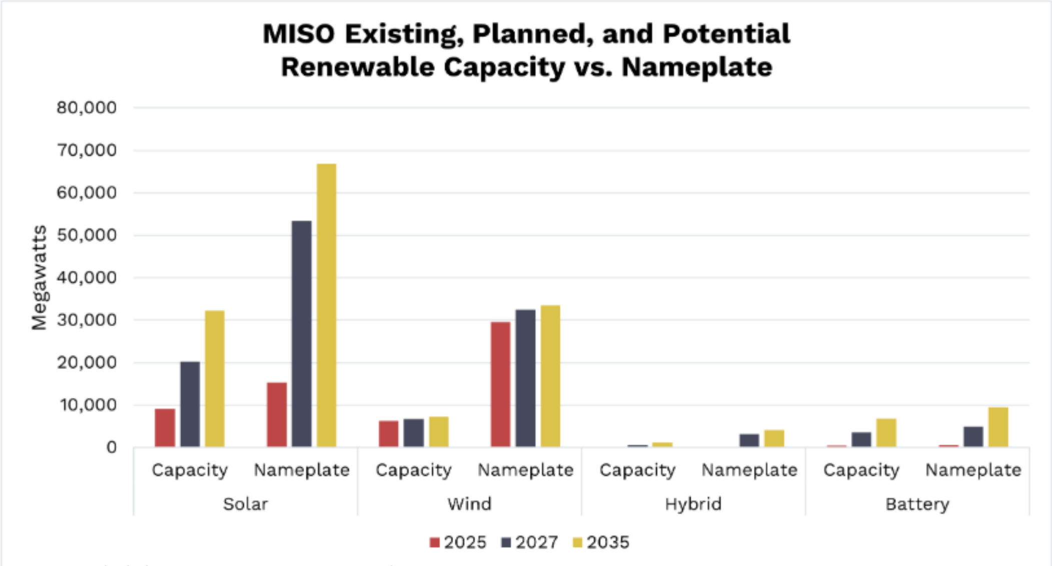
Available energy

Megawatts produced over a defined set of time.

Why does it matter?

A system may appear adequate by nameplate or capacity values but still face risk if fuel, weather, outages, or transfers limit energy availability


PJM Existing, Planned, and Potential Renewable Summer Capacity vs. Nameplate


MISO Existing, Planned, and Potential Renewable Capacity vs. Nameplate

Source: ReliabilityFirst 2026 Resource Adequacy Report
https://feature.rfirst.org/resource-adequacy-report-2026/index.html

BALANCING RESOURCES & DEMAND

Key question: Do we have enough resources to keep the lights on in the future?

Applicable Risks

1) Resource retirements outpace resource additions
2) Demand outpaces resource additions

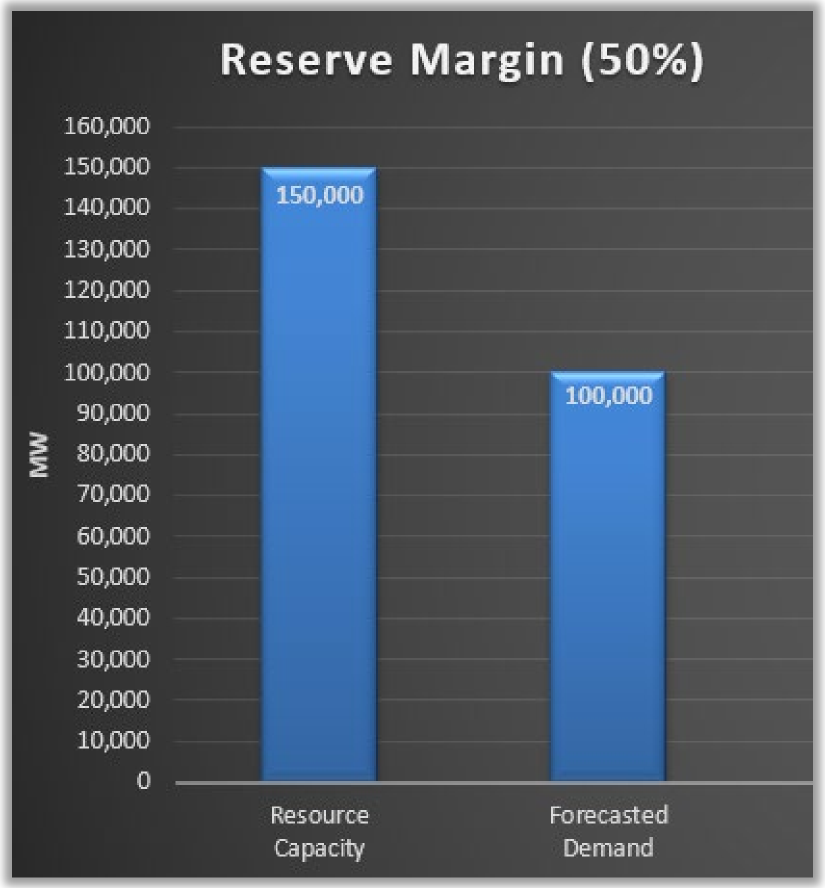
Are policy, market, permitting, and interconnection paths aligned so replacement resources arrive before shortages occur?

RESOURCE MARGINS

Reserve Margin

- Amount of resource capacity that exceeds demand

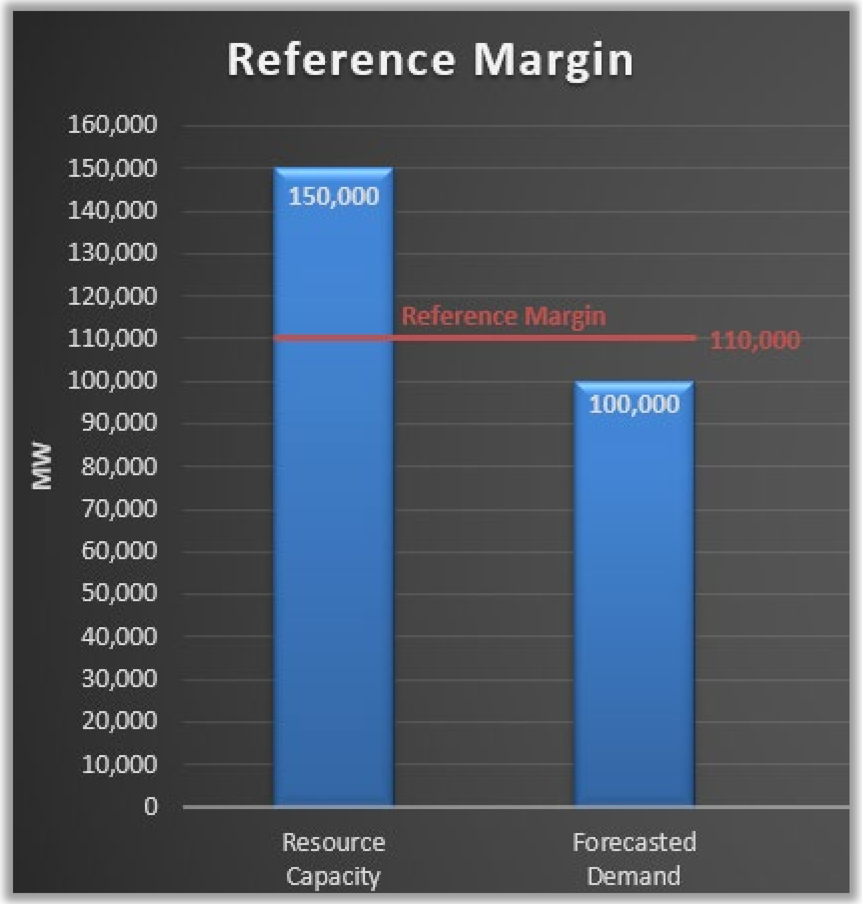
How much of a buffer does my area have?



Reference Margin

- Represents acceptable level of risk for resource planning

Is my buffer sufficient?



RESOURCE ADEQUACY - TAKEAWAYS

Results are constantly in flux: Pace of change in resource additions and retirements plus demand forecasts

- Resources are represented based on output profile impacted by outages, weather, and fuel availability
- Important to plan for resources to be greater than demand ***AND*** the reserve margin
- Reduce uncertainty with accurate forecasting
  - Can generation be built in time?
  - Will load develop as forecasted?
- Reliable portfolio considers how resources perform together during high-risk periods
- Measures like Demand Response can be used to balance resource shortfalls

Energy Assessments

Is there enough energy to supply demand through sustained events?

WHY IS IT IMPORTANT?

A system may have adequate reserve margins but still face risks if fuel, weather, outages, or transfers limit sustained energy availability.

Energy shortfall risk is shifting away from peak conditions

Extreme weather can impact renewable output, thermal plant performance, and increase risk of transmission outages

Operational complexity increases with flexible demand, fuel storage coordination, and optimizing battery dispatch

Wide-area events can impact ability to deliver energy between regions

DATA UTILIZED

Model

- "Pipe and bubble" – Not as complex as planning or operational models

Demand Inputs

- Forecasted hourly load profiles
- Demand Response assumptions

Transmission Inputs

- Transfer capabilities between areas
- Import/export assumptions

Weather Inputs

- Historical weather and temperatures

Resource Inputs

- Conventional resource capacity and operating characteristics
    - Forced outage rates and maintenance schedules
- Renewable nameplate values
- Renewable resource profiles (i.e., hydro, solar, and wind)
- Energy Storage nameplate, duration, and dispatch assumptions

Operational Inputs

- Reserve requirements
- Ramp rate and minimum run times
- Seasonal and extreme operating assumptions

PROBABILISTIC RISK METRICS

Loss of Load Expectation LOLE

How often?

Expected number of days in a year when supply could fall short at least once. It is a frequency metric. Common shorthand: 0.1 days/year, often described as “1 day in 10 years.”

Loss of Load Hours LOLH

How long?

Expected number of hours in a year when demand could exceed available supply. It gives a more detailed view than counting days, because it looks hour by hour.

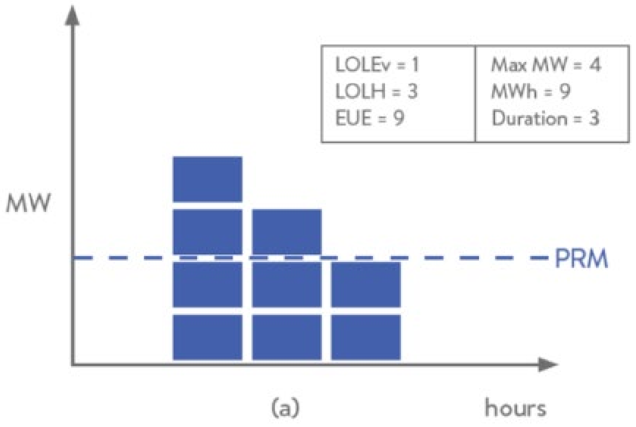
Expected Unserved Energy EUE

How big is the impact?

Expected amount of energy customers would not receive during shortage events, usually shown in MWh or GWh. It captures severity, not just occurrence.

No Perfect Metric

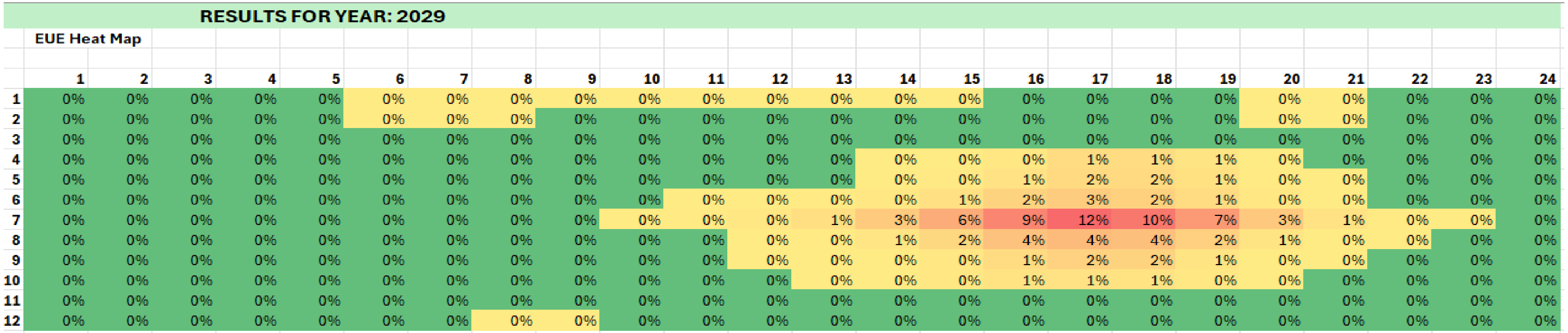
- No single metric tells the whole story.
- LOLE shows frequency, LOLH shows duration, and EUE shows severity.
- Together, they give a clearer picture of reliability risk and the types of solutions that may be needed.



Source: Resource Adequacy Philosophy: A Guide to Resource Adequacy Concepts and Approaches

OUTPUT FROM ENERGY ANALYSIS

Think of the EUE heat map as a weather radar for energy risk. Reds and yellows indicate periods where the model expects a higher amount of unserved energy. It helps us identify when energy shortages are most likely to occur, how severe they may be, and where additional resources or operational actions may be needed.



RESULTS FOR YEAR: 2029

EUE Heat Map

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	2%	1%	0%	0%	0%	0%	0%
6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	3%	2%	1%	0%	0%	0%	0%	0%
7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	3%	6%	9%	12%	10%	7%	3%	1%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	4%	4%	4%	2%	1%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	2%	1%	0%	0%	0%	0%	0%
10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%
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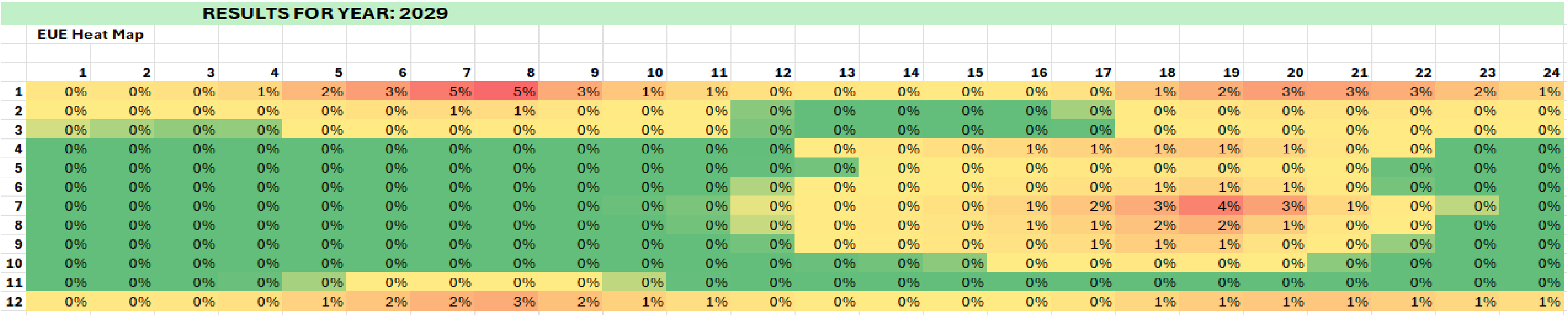

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3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	0%	0%	0%	0%
5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%
7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	3%	4%	3%	1%	0%	0%	0%
8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	2%	2%	1%	0%	0%	0%	0%
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%
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11	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12	0%	0%	0%	0%	1%	2%	2%	3%	2%	1%	1%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	1%	1%

Solutions for Consideration

What can be implemented to alleviate identified resource and energy shortfalls?

SOLUTIONS FOR CONSIDERATION

Fast-Track Resources in PJM and MISO

Both initiatives accelerate interconnection review for resources intended to address near-term reliability needs.

PJM

RRI

RELIABILITY RESOURCE INITIATIVE

- One-time expedited path for shovel-ready resources that can contribute to reliability.
- Projects are evaluated for reliability contribution and commercial-operation-date viability.
- Selected projects enter PJM's Transition Cycle #2 study process.

MISO

ERAS

EXPEDITED RESOURCE ADDITION STUDY

- Temporary, targeted process for resources identified as needed for resource adequacy.
- Designed to speed interconnection studies for qualifying generation additions.
- Revised after initial FERC concerns to provide a more limited and targeted process.

ENERGY ANALYSIS TAKEAWAY

Fast-track resources may improve future adequacy, but current studies may not yet reflect final project selection, interconnection results, required transmission upgrades, or commercial operation dates.

SOLUTIONS FOR CONSIDERATION

- Accept the identified risks during extreme events (assuming other reliability thresholds are met)
- Construct local generation
- Increase Demand Response
- Increase transfer capability to neighbors with surplus resources
  - Transmission infrastructure upgrades
  - Dynamic line ratings (DLR)
  - Power flow control devices

Grid-enhancing Technologies (GETs)

Source: NERC Interregional Transfer Capability Study (ITCS) Strengthening Reliability Through the Energy Transformation, Chapter 5, Page 45

Resource Reference Library

Four trusted starting points for regional assessments, industry methods, and practitioner guidance

RF

ReliabilityFirst

Regional assessments and reports for the RF footprint

START HERE

RF Resource Center

2026 Resource Adequacy Report

BEST FOR

Regional
Seasonal
Resource adequacy

NERC

NERC

North American reliability assessments and risk outlooks

START HERE

NERC Assessments

2025 Long-Term Reliability Assessment

BEST FOR

LTRA
Seasonal
Risk trends

ESIG

Energy Systems Integration Group

Modern resource adequacy methods and grid-integration guidance

START HERE

Reports & Briefs

Redefining Resource Adequacy

BEST FOR

Chronology
Multi-metric
Weather years

EPRI

Electric Power Research Institute

Research, concepts, tools, and practitioner resources

START HERE

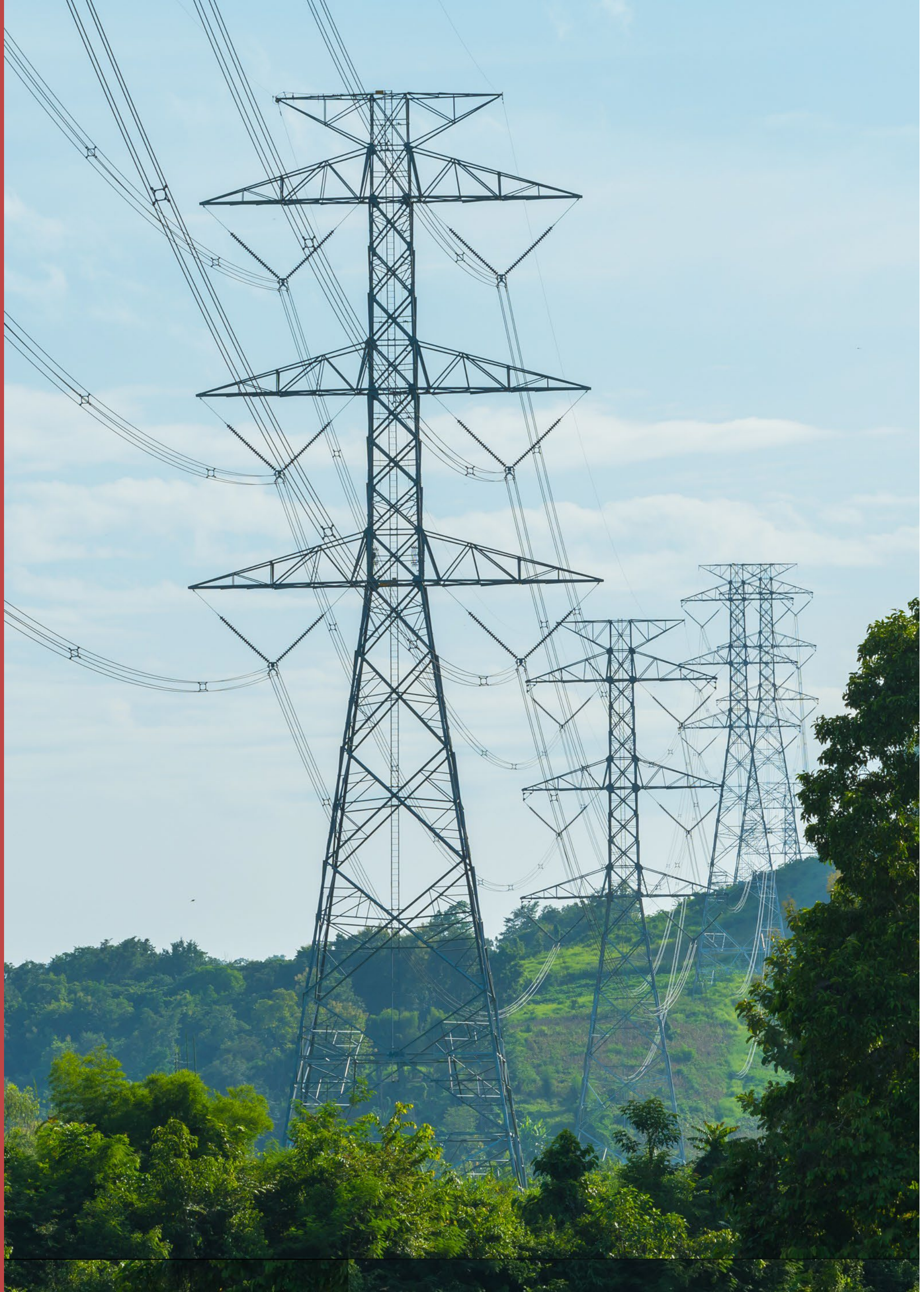
Resource Adequacy Hub

Assessment Resource Center

BEST FOR

Frameworks
Tools
Research

Click any underlined link



QUESTIONS & ANSWERS

Tim Fryfogle

tim.fryfogle@rfirst.org

SESSION BREAK

Flexible Load as a Reliability Resource: Opportunities and Challenges

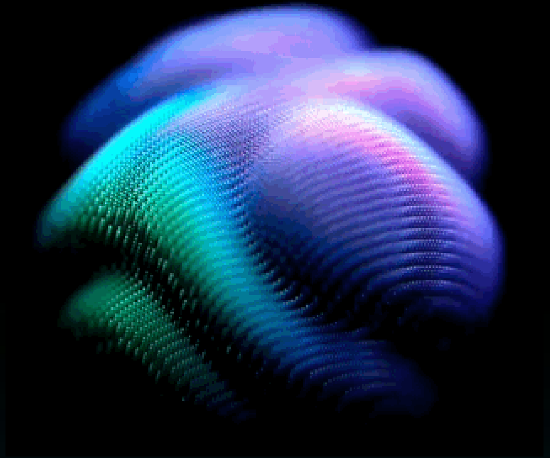
Dr. Aidan Tuohy

Director, Electric Power Research Institute

(EPRI)

Flexible Load as a Reliability Resource

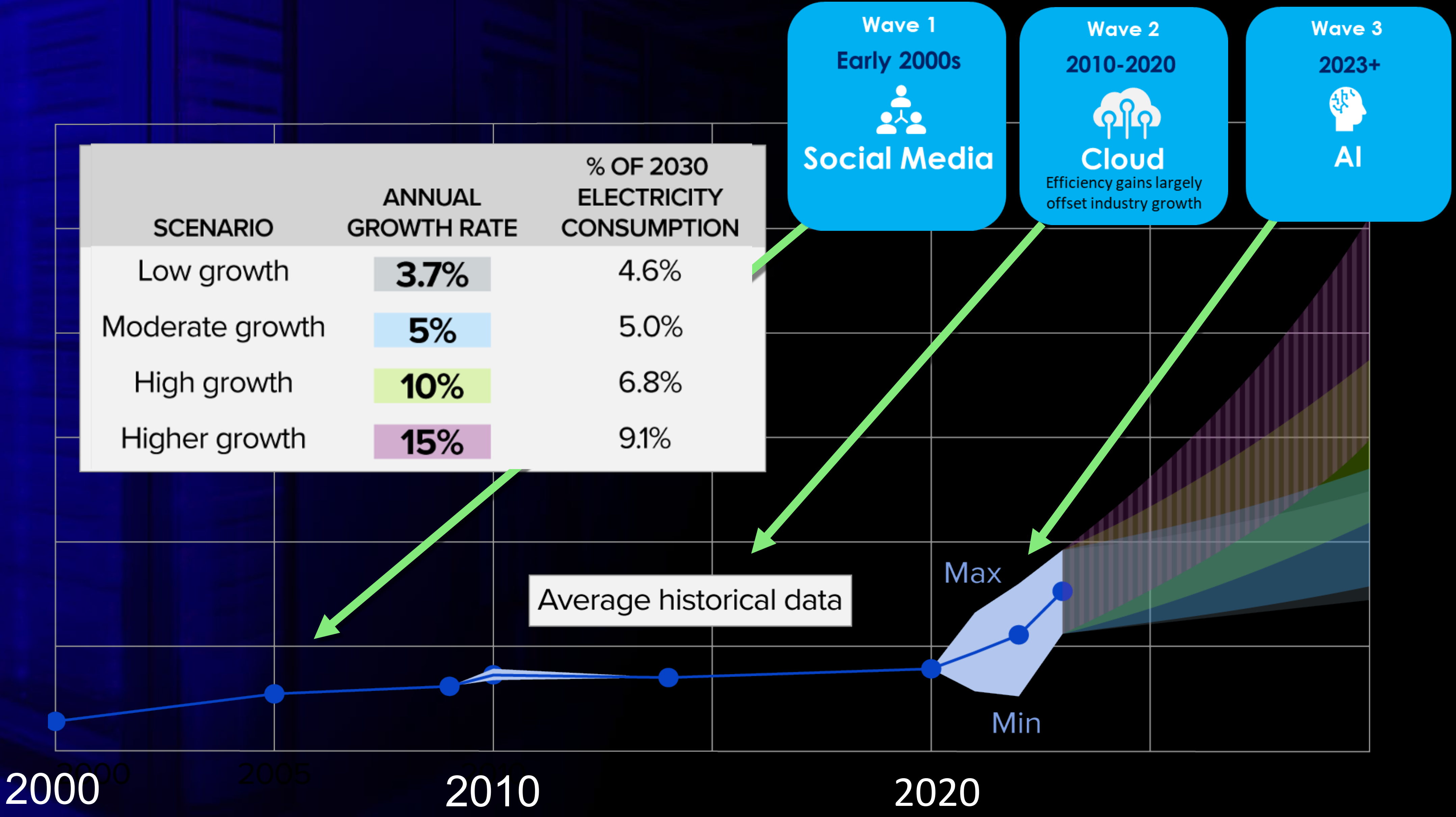
Opportunities and Challenges



Aidan Tuohy, Director R&D, EPRI

Reliability First Fall Reliability and Security Summit
Sept 14-16, 2026
Colombus, OH

AI is Driving a Third Wave of Data Center Growth



Wave 1
Early 2000s
Social Media

Wave 2
2010-2020
Cloud
Efficiency gains largely offset industry growth

Wave 3
2023+
AI

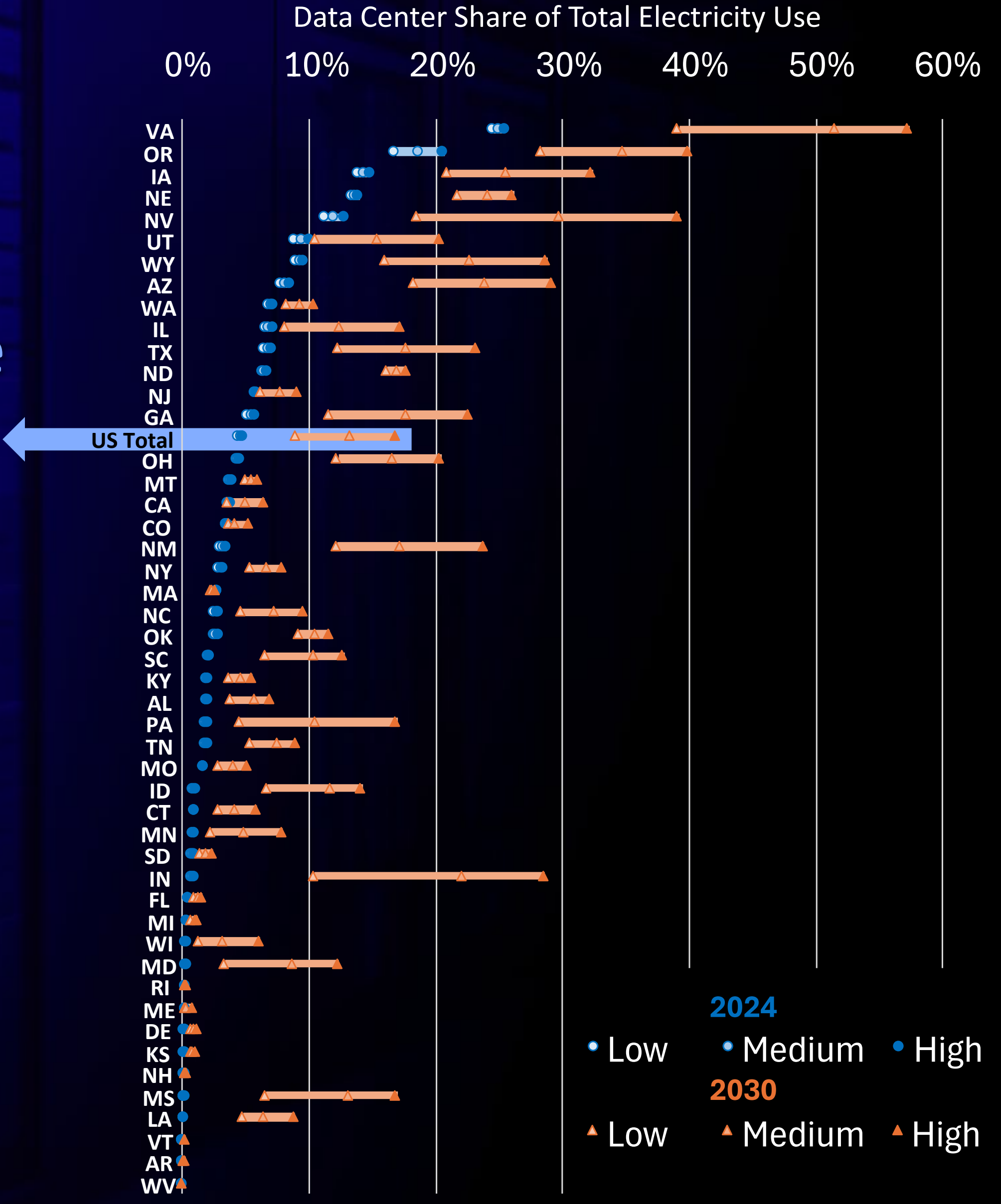
SCENARIO	ANNUAL GROWTH RATE	% OF 2030 ELECTRICITY CONSUMPTION
Low growth	**3.7%**	4.6%
Moderate growth	**5%**	5.0%
High growth	**10%**	6.8%
Higher growth	**15%**	9.1%

New Insights from EPRI on U.S. Datacenter Growth

U.S. estimated share

4-5% in 2024

9-17% in 2030



Source: EPRI Powering Intelligence 2026

What Can We Do to Meet This Demand Growth?

EXTEND THE LIFE OF TODAY'S ASSETS.

INCREASE THE UTILIZATION OF TODAY'S ASSETS.

MAKE ROOM TO BUILD NEW ASSETS.

DCFlex Optimize Data Center Operational Flexibility to Help Strengthen the Grid

10+
demo sites

ARIZONA, U.S.
NORTH CAROLINA, U.S.
PARIS, FRANCE
VIRGINIA, U.S.
ILLINOIS, U.S.
TEXAS, U.S.
LONDON, U.K.

DCFlex Workstreams

- Flexible Data Center Design 01
- Transformational Utility Programs 02
- Grid Operational Flexibility 03
- Planning & Portfolio Readiness 04
- Distribution Data Centers 05

The DCFlex participant panel actively collaborates with regulators, academia, and industry stakeholders – both to share leading practices and insights, and to incorporate diverse perspectives that strengthen the initiative's direction and impact.

Learn More:
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DCFlex Collaboration

DCFlex

Developers

COMPASS datacenters

QTS

Hyperscalers

Google

Meta

Microsoft

IPP's

CALPINE

Constellation

nrg

VISTRA

ISO/RTO

California ISO

CENACE Centro Nacional de Control de Energía

ercot Your Power. Our Promise.

ieso Connecting Today. Powering Tomorrow.

smart KPX

MISO

NESO National Energy System Operator

pjm

SPP Southwest Power Pool

Technology Providers

CATERPILLAR

JENBACHER INNIO

KRAKEN

NVIDIA

PADO

Schneider Electric

Advisory & Finance

EY

ING

KPMG

Engineering & Construction

CRIEPI Central Research Institute of Electric Power Industry

QUANTA

Ulteig

wesco

Utilities

aes

Alliant Energy

American Electric Power

aps

Bonneville Power Administration

CenterPoint Energy

ΔEH

Dominion Energy

DTE

Duke Energy

East Kentucky Power Cooperative

A Touchstone Energy Cooperative

ENOWA NEOM

entergy

exelon

Georgia Transmission

KEPCO

LES

LCRA Energy • Water • Community Services

nationalgrid

Nebraska Public Power District

Always there when you need us

New York State of Opportunity NY Power Authority

OglethorpePower

PGE

ppl

PSEG

REC Rayburn Electric Cooperative

RTE

RWE

SRP

Southern Company

TVA Tennessee Valley Authority

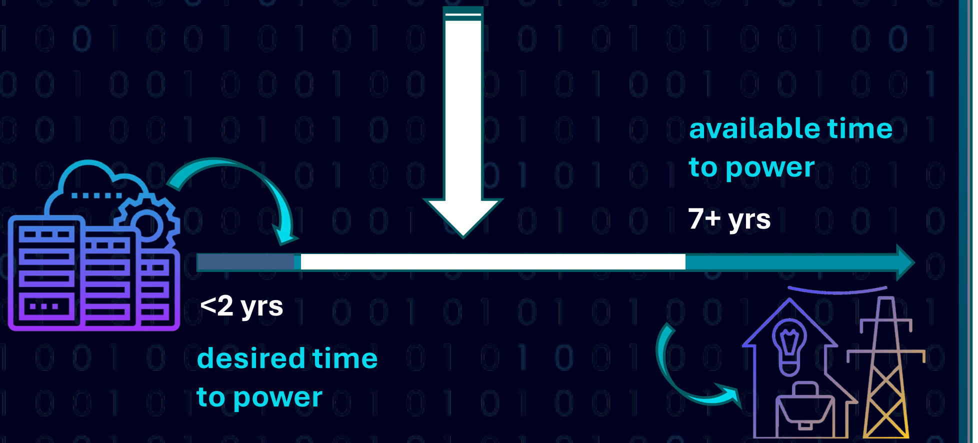
United Power

Your Touchstone Energy Cooperative

Powering AI

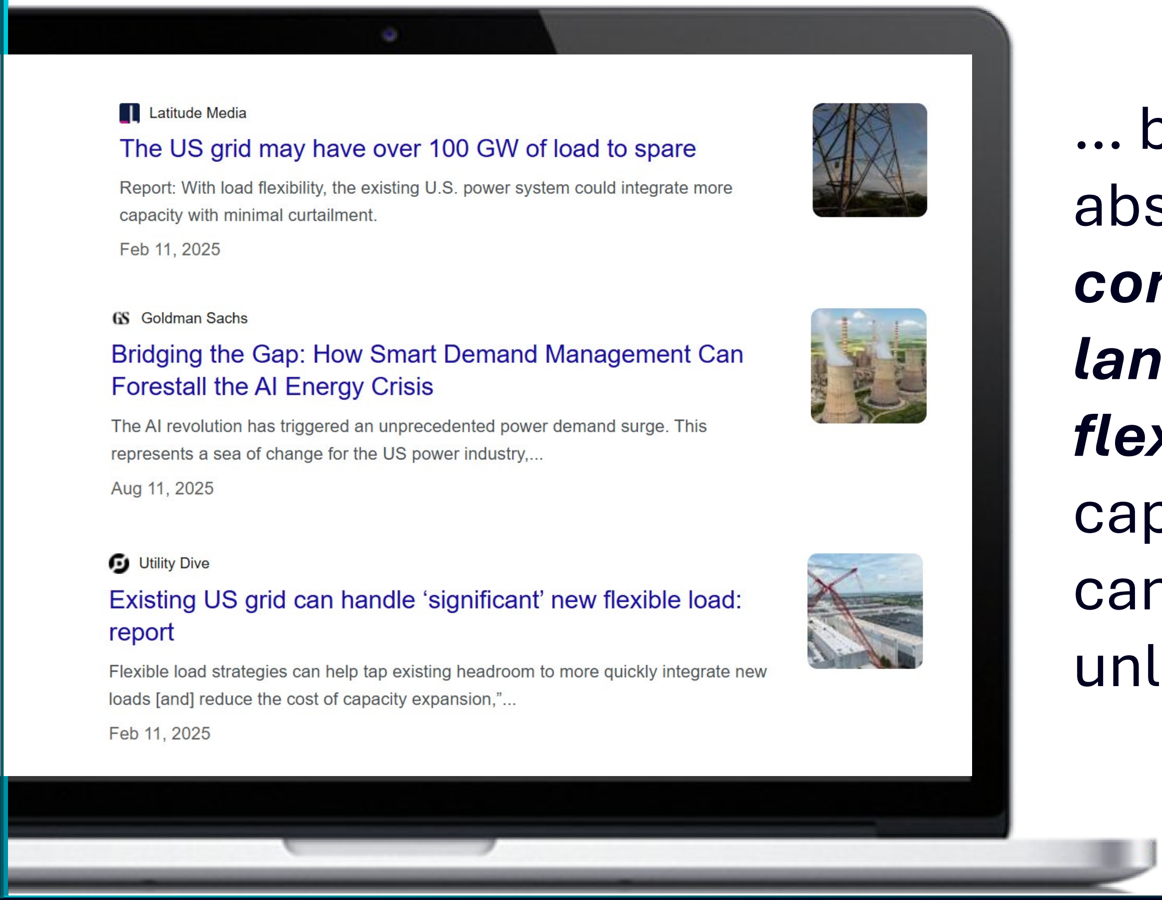
CHALLENGE

gap between data centers need & capacity availability



SOLUTION

Grid-integrated Flexible Load



Latitude Media

The US grid may have over 100 GW of load to spare

Report: With load flexibility, the existing U.S. power system could integrate more capacity with minimal curtailment.

Feb 11, 2025

Goldman Sachs

Bridging the Gap: How Smart Demand Management Can Forestall the AI Energy Crisis

The AI revolution has triggered an unprecedented power demand surge. This represents a sea of change for the US power industry,...

Aug 11, 2025

Utility Dive

Existing US grid can handle 'significant' new flexible load: report

Flexible load strategies can help tap existing headroom to more quickly integrate new loads [and] reduce the cost of capacity expansion,"...

Feb 11, 2025

… but in the absence of *a* ***common language on flexibility*** grid capacity cannot be unlocked

FLEX MOSAIC

INCREASING FLEXIBILITY →

	CLASS A	CLASS B	CLASS C	CLASS D	CLASS E
	Critical Peaking	Peaking	Prolonged	Fast	Fully Grid Responsive
🔔	Hours to day-ahead	Hours to day-ahead	Day Ahead	≥ 5 min	≥ 5 min
⏰	≤ 5 Hours	≤ 5 Hours	≥ 5 h-days	≤ 5 Hours	Unbounded
📅	≤ 1% ≤ 90 h	2 - 10% 100 – 800 h	≤ 10% ≤ 800 h	2 – 10% 100 – 800 h	Unbounded
	respond to *rare* scarcity events 5 hours or less	respond to *frequent* scarcity events 5 hours or less	A + B + respond to *prolonged* events, up to 24+hrs	A + B + provide fast response with short notifce	Fully *grid responsive*

World's largest cross-sector collaborative on flexibility unveils

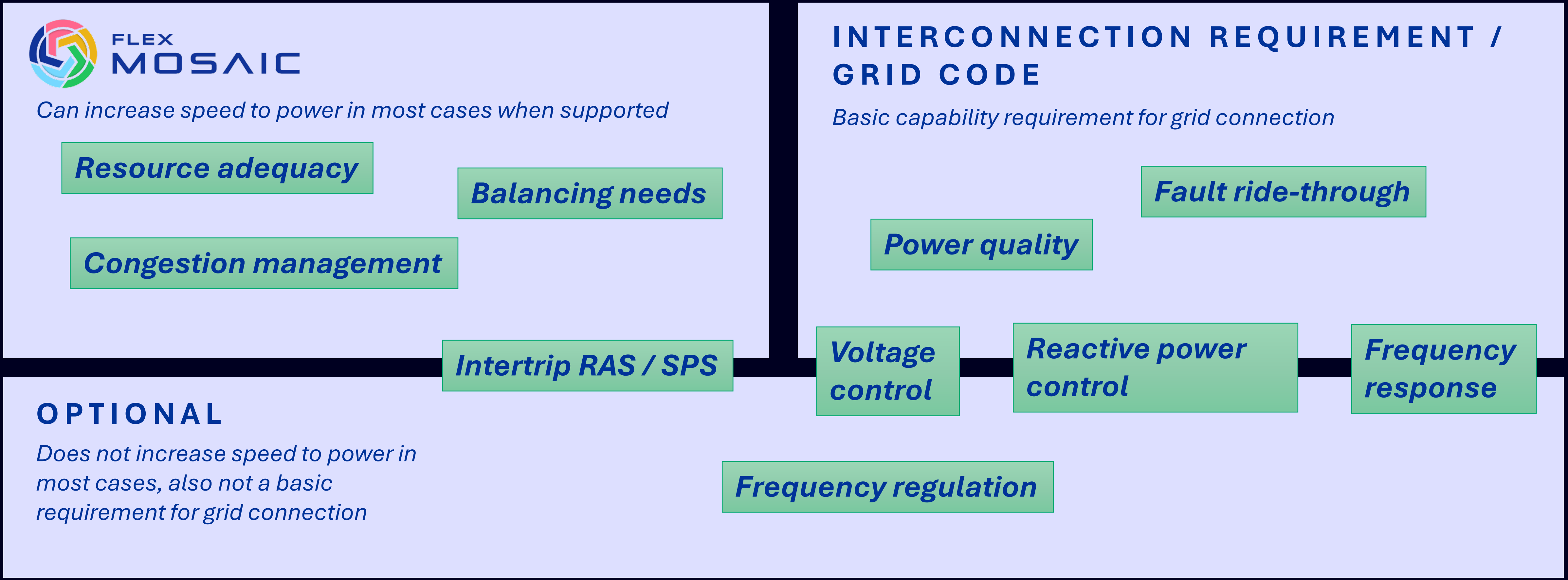
Common Flexibility Classification

to unlock grid capacity without compromising reliability and affordability

🔔	Notification Window
⏰	Activation Period
📅	Annual Utilization

Flex MOSAIC™ in Context

What is a requirement to connect to the network vs. an optional attribute that can support speed to power?



FLEX MOSAIC

Can increase speed to power in most cases when supported

Resource adequacy

Balancing needs

Congestion management

Intertrip RAS / SPS

INTERCONNECTION REQUIREMENT / GRID CODE

Basic capability requirement for grid connection

Fault ride-through

Power quality

Voltage control

Reactive power control

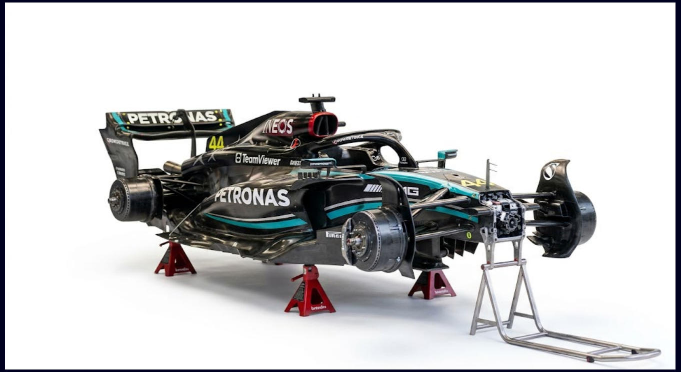
Frequency response

OPTIONAL

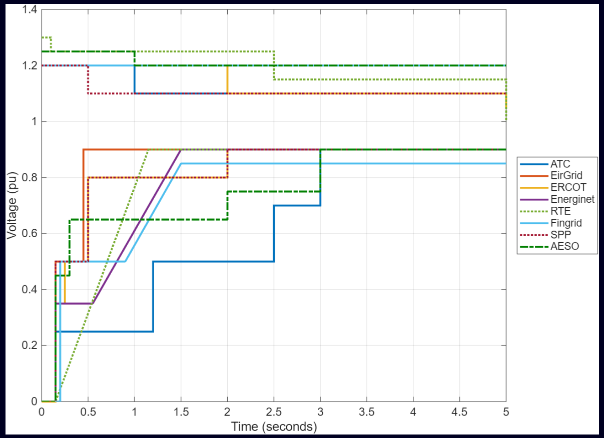
Does not increase speed to power in most cases, also not a basic requirement for grid connection

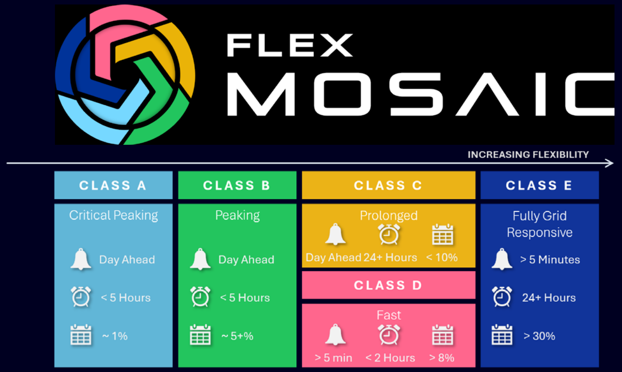
Frequency regulation

Certain technologies can **unlock flexibility and interconnection requirements simultaneously**



The Formula 1	Tires needed to drive on track	Better performance on different track
The Data Center	Grid codes needed for interconnection	Higher capacity on constrained grid





CLASS A
Critical Peaking
Day Ahead
< 5 Hours
~ 1%

CLASS B
Peaking
Day Ahead
< 5 Hours
~ 5+%

CLASS C
Prolonged
Day Ahead 24+ Hours < 10%

CLASS D
Fast
> 5 min < 2 Hours > 8%

CLASS E
Fully Grid Responsive
> 5 Minutes
24+ Hours
> 30%

Flex MOSAIC™ - Common Program Names

🔔 Notification Window
⏰ Activation Period
📅 Annual Utilization

CLASS A

Critical Peaking

🔔 4 h - Day Ahead
⏰ ≤ 5 Hours
📅 ~ 1%

COMMON NAMES

- Emergency Demand Response, Reliability Demand Response
- Some Capacity Market Obligations
- Resource Adequacy

CLASS B

Peaking

🔔 Day Ahead
⏰ ≤ 5 Hours
📅 2-10%

COMMON NAMES

- Reliability Demand Response, Economic Demand Response
- Capacity Market Obligations
- Interruptible Rates
- Congestion Management

CLASS C

Prolonged

🔔 Day Ahead
⏰ ≥ 5 h-days
📅 <10%

COMMON NAMES

- Transmission Outages
- Multi-day look-ahead

CLASS D

Fast

🔔 ≥ 5 min
⏰ ≤ 5 Hours
📅 2-10%

COMMON NAMES

- Real-time procurement of wholesale market products or services

CLASS E

Fully Grid Responsive

🔔 > 5 Minutes
⏰ Unbounded
📅 Unbounded

COMMON NAMES

- Day-ahead or Intra-day Procurement with Real-time Deployment of wholesale market products and services
- Hourly Pricing Retail Programs

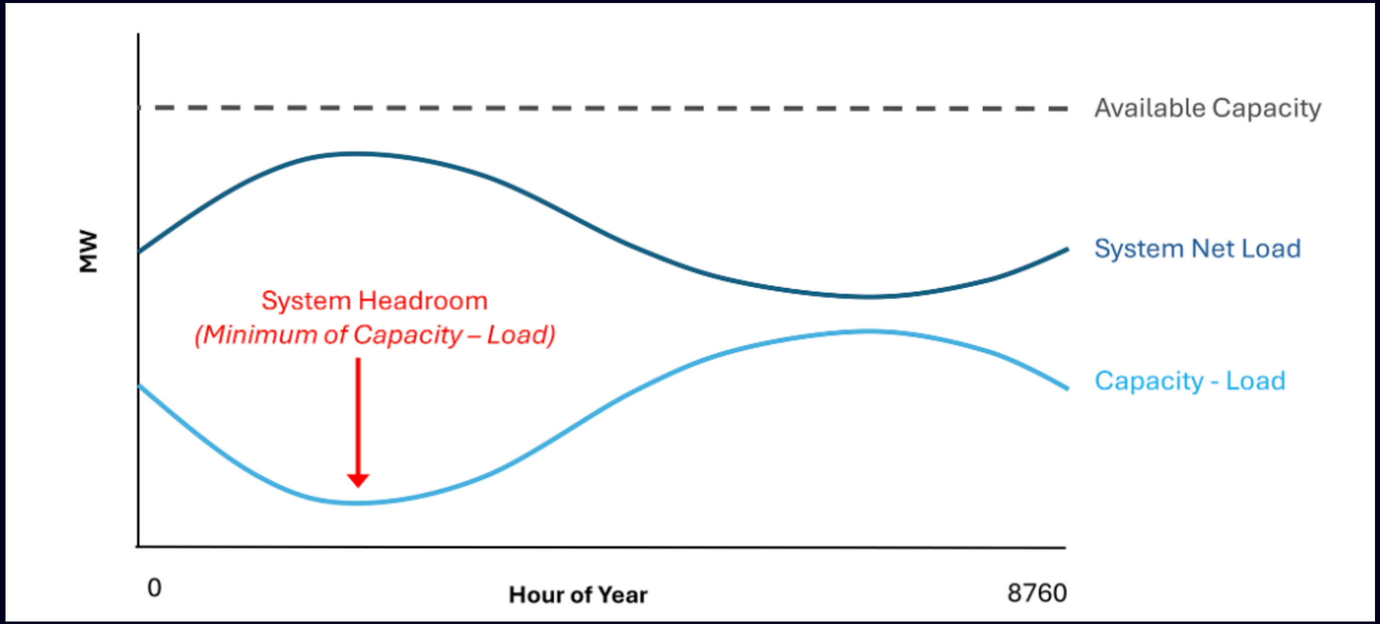
Assessing System Headroom for Integrating Data Center Load

EPRI Lead: Nidhi Santen

WHAT IS HEADROOM?

The additional load (MW) a power system can integrate across all time periods before violating reliability requirements.

Total system headroom depends on time, location, operating conditions, reliability requirements, **and flexibility characteristics of the new load**. It's the minimum of *available* capacity less net load over a given window of time.



WHY WE CARE

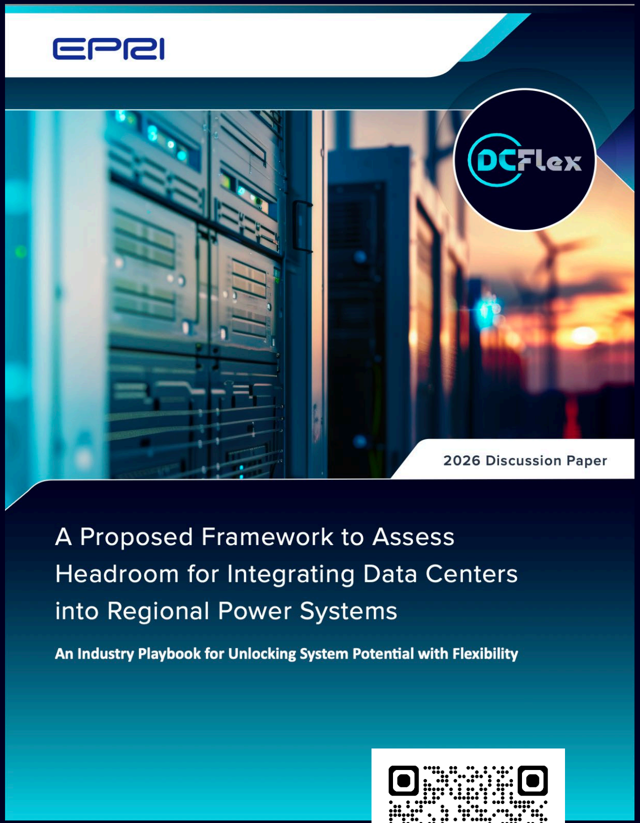
Speed to power without compromising reliability

Data centers are requesting power faster than new transmission, generation, or substation infrastructure can be built. It is important to understand where existing systems can safely accommodate load and where flexibility can unlock additional capacity.

HOW HEADROOM ASSESSMENTS MAY ENABLE SPEED TO POWER

Signals, planning guidance, and the “handshake”

Utilities and system operators can translate the outputs of a headroom study into pre-interconnection application signals for data center and large load developers: where headroom exists, what flexibility is most valuable, and how flexible operations may afford additional MW connection. Developers can use this information in their investment, design, and locational decisions. **Interconnection applications become aligned with grid needs.**



2026 Discussion Paper

A Proposed Framework to Assess Headroom for Integrating Data Centers into Regional Power Systems

An Industry Playbook for Unlocking System Potential with Flexibility

www.headroom.epri.com

HEADROOM FRAMEWORK 101

A practical playbook to estimate system headroom

- The Headroom Framework includes step-by-step guidance to calculate system headroom.
- It provides a standard, repeatable process for utilities and system operators to identify baseline headroom and how much additional headroom may unlocked by flexible DC operations.
- It is compatible with existing planning models and adaptable to a system's planning journey, data availability, and market & reliability criteria.
- It can be used to support internal planning processes and external engagement with developers.
- Standardization enables 3 Cs:
  - consistency and a common language between utilities/ISOs and developers
  - confidence in assessment outputs, and
  - collaborative industry learning in a fast-paced environment.

WHAT IT ASSESSES

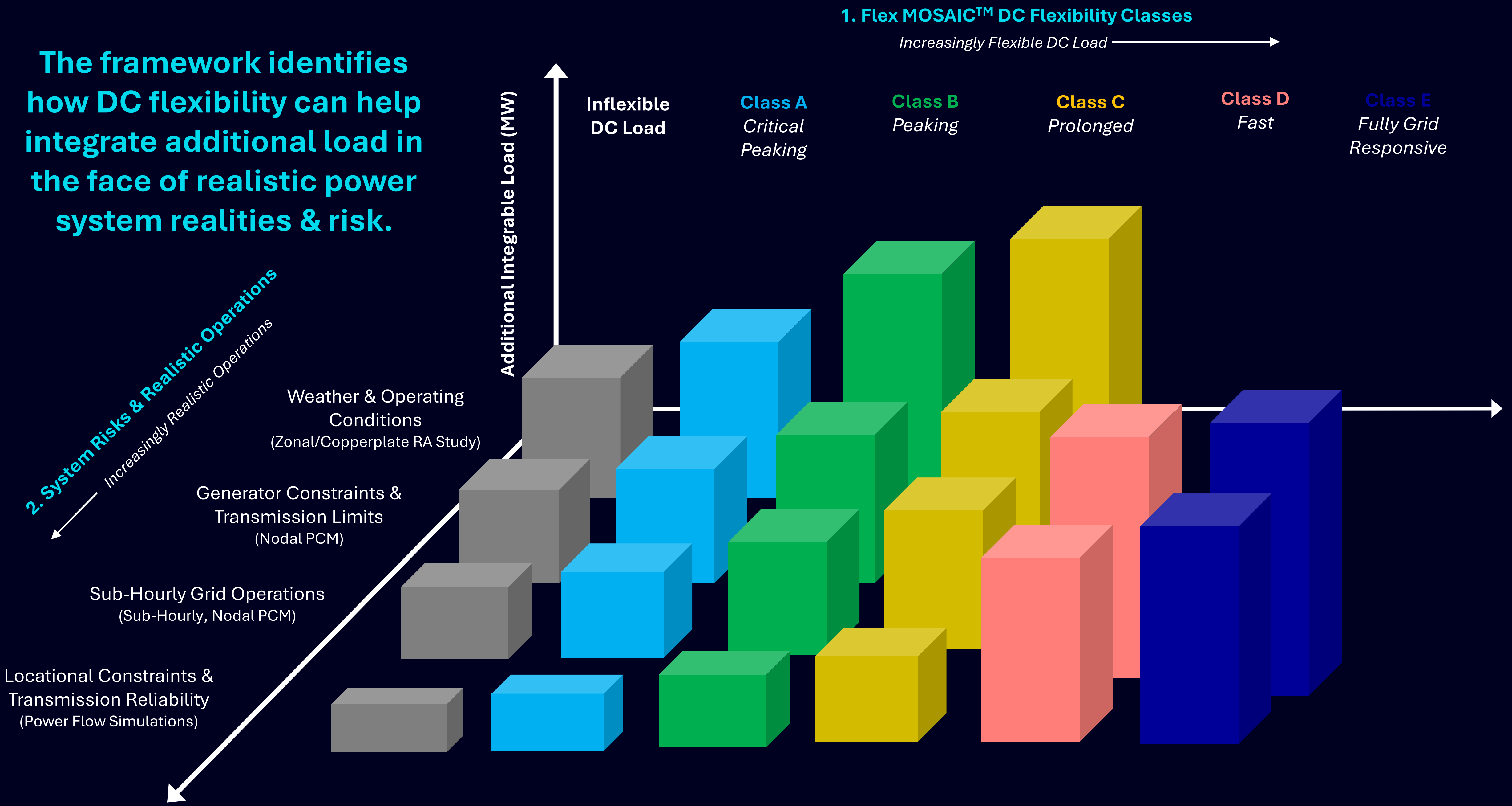
More than peak-load capacity

The framework assesses headroom along two key dimensions:

1. **Realistic power system characteristics** across relevant periods: system adequacy, generator constraints, transmission limits, fast-response operations, locational risk, and transmission reliability; and

2. **Flexibility potential of the additional load**: the full range of Flex MOSAIC^{TM} data center classes A-E, offering critical peaking to fully responsive grid support.

The framework identifies how DC flexibility can help integrate additional load in the face of realistic power system realities & risk.



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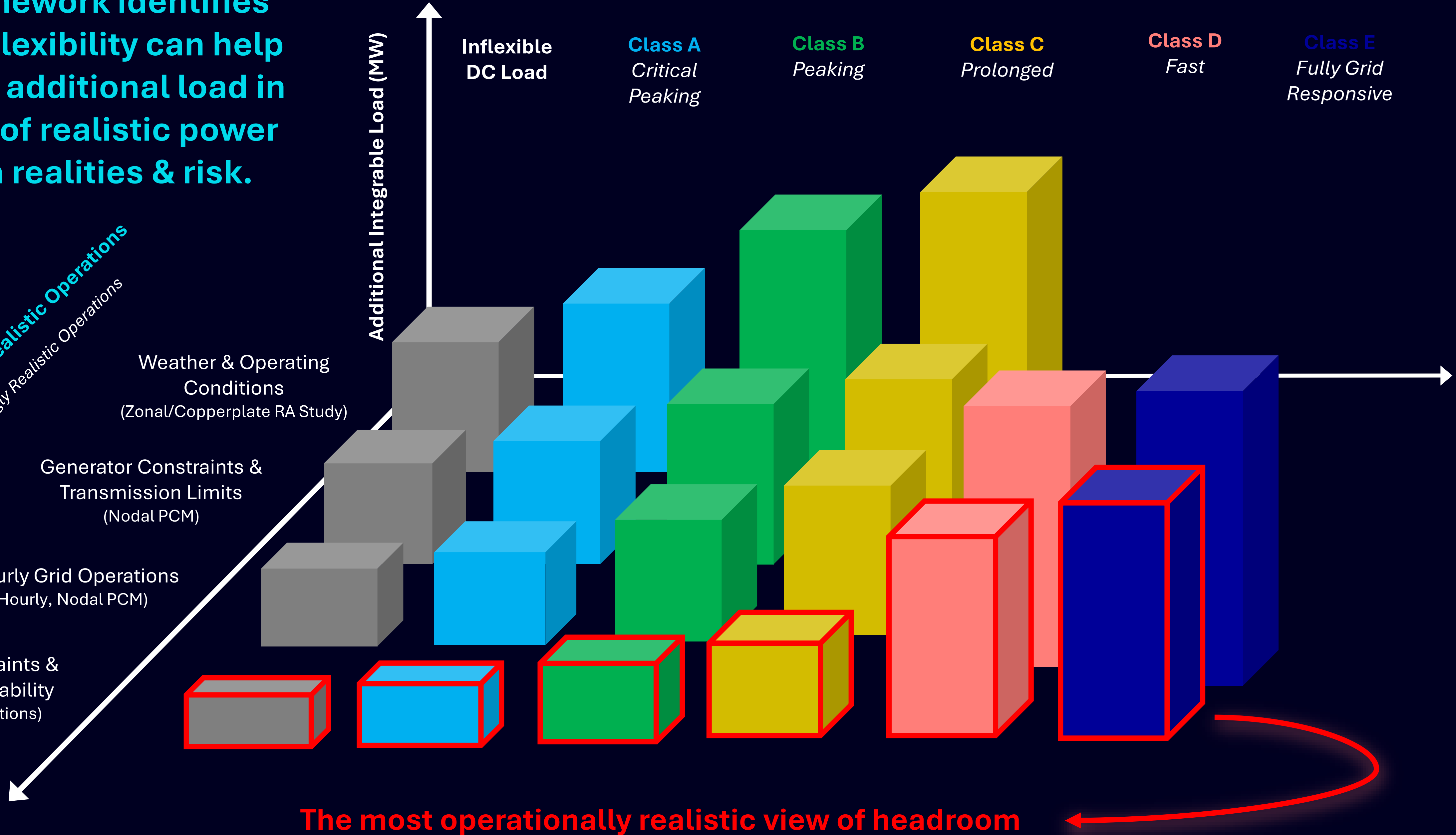

1. Flex MOSAIC^{TM} DC Flexibility Classes

Increasingly Flexible DC Load →

Inflexible DC Load

Class A *Critical Peaking*

Class B *Peaking*

Class C *Prolonged*

Class D *Fast*

Class E *Fully Grid Responsive*

Additional Integrable Load (MW)

2. System Risks & Realistic Operations

Increasingly Realistic Operations

Weather & Operating Conditions
(Zonal/Copperplate RA Study)

Generator Constraints & Transmission Limits
(Nodal PCM)

Sub-Hourly Grid Operations
(Sub-Hourly, Nodal PCM)

Locational Constraints & Transmission Reliability
(Power Flow Simulations)

The most operationally realistic view of headroom

EXPECTED OUTPUTS FROM A HR ANALYSIS

Primary—System Headroom Ladder & the Value of DC Flexibility

- Maximum *firm* load (MW) by location (e.g., zone, node) the system can integrate
- Maximum *non-firm* integrable load by location and by level of flexibility (i.e., flexibility ladder).
- Insight into the potential value of different types of flexible data centers in the power system

Secondary—Power System Operations, Flexibility Needs, & Sensitivity

- Simulation results showing operational characteristics of each type of flexible DC
- Number of flexibility events (i.e., curtailment) by location
- Depth (MW) and duration of flexibility events by event and location
- Deep understanding about the driver of flexibility needs (e.g., congestion, reliability thresholds)

MANY OPEN HEADROOM QUESTIONS

- How should a headroom analysis adapt for **vertically integrated utilities versus those operating within organized markets?**
- What analytical phases should be in a **headroom analysis vs. an interconnection study** after application? What may or may not be strategic for a utility to disclose pre-application?
- Should a "pre-application" signal include information about available **firm capacity, non-firm capacity, or both**?
- How **often** does a headroom assessment have to be updated for it to be useful to a utility/ISO and/or to a data center/large load developer?
- Are there **computational advances** (e.g., AI orchestration, machine learning) that can support conducting these studies faster
- Is "Headroom" the **preferred term** for these assessments? Another preferred phrase?

Interconnection of Data Centers TOP and DCFlex Highlights

Lead: Parag Mitra

Key Topics being Addressed

01 **Modeling Guidance and Model Development**

02 **Voltage Ride Through Determination and Testing**

03 **Load Oscillation Impacts, Monitoring, and Mitigation**

04 **Interconnection Studies for Flexible Loads**

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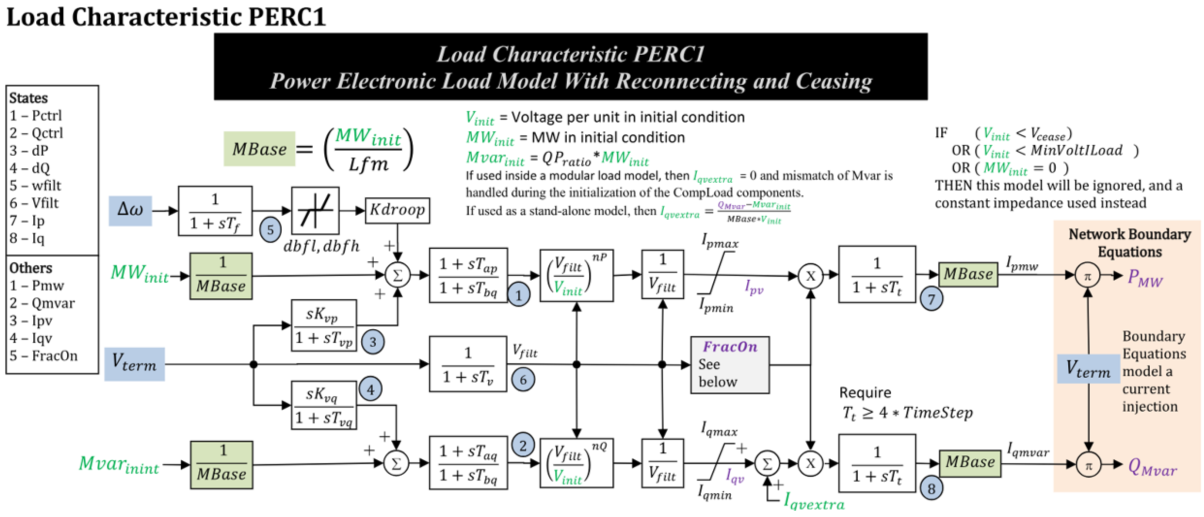
Model Development – Phasor and EMT

Phasor Domain Model


Load Characteristic PERC1

Load Characteristic PERC1
Power Electronic Load Model With Reconnecting and Ceasing

V_{init} = Voltage per unit in initial condition
MW_{init} = MW in initial condition
$Mvar_{init} = QP_{ratio} * MW_{init}$
If used inside a modular load model, then $I_{qvextra} = 0$ and mismatch of Mvar is handled during the initialization of the CompLoad components.
If used as a stand-alone model, then $I_{qvextra} = \frac{Q_{Mvar} - Mvar_{init}}{MBase * V_{init}}$

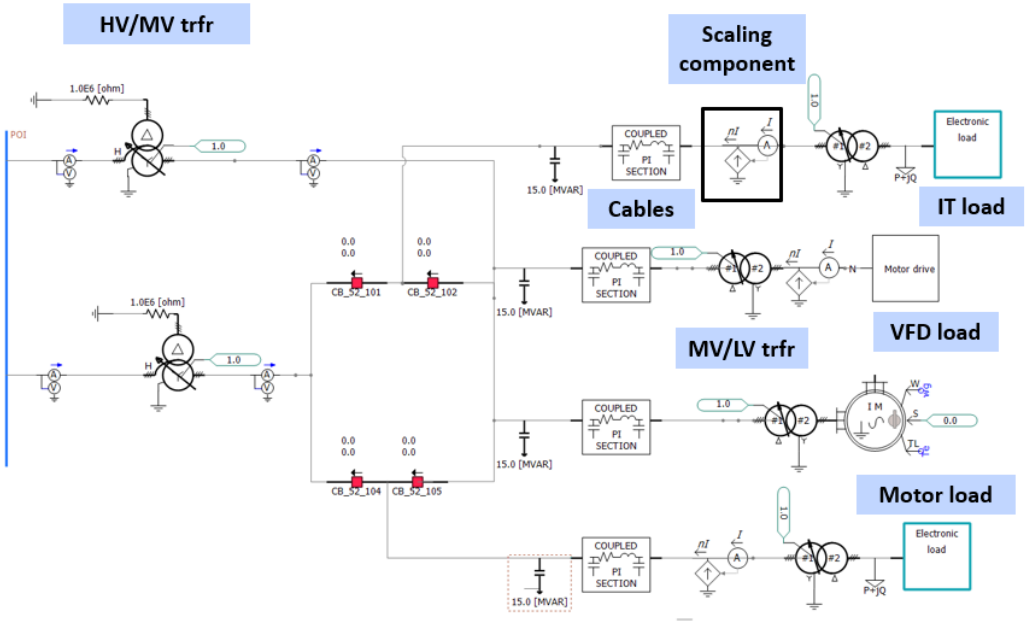
IF ($V_{init} < V_{cease}$)
OR ($V_{init} < MinVoltILoad$)
OR ($MW_{init} = 0$)
THEN this model will be ignored, and a constant impedance used instead

States
1 – Pctrl
2 – Qctrl
3 – dP
4 – dQ
5 – wfilt
6 – Vfilt
7 – Ip
8 – Iq

Others
1 – Pmw
2 – Qmvar
3 – Ipv
4 – Iqv
5 – FracOn

Require $T_t \geq 4 * TimeStep$

EMT Model



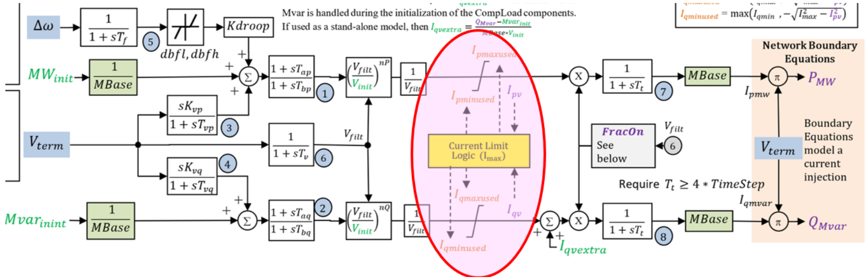
Phasor domain models are effective for studying load disconnection and reconnection impacts on the bulk power system.

Allows us to identify emerging reliability risks related to data centers and parameterize and refine our phasor models

Improvements to PERC1 (PERC2 model)

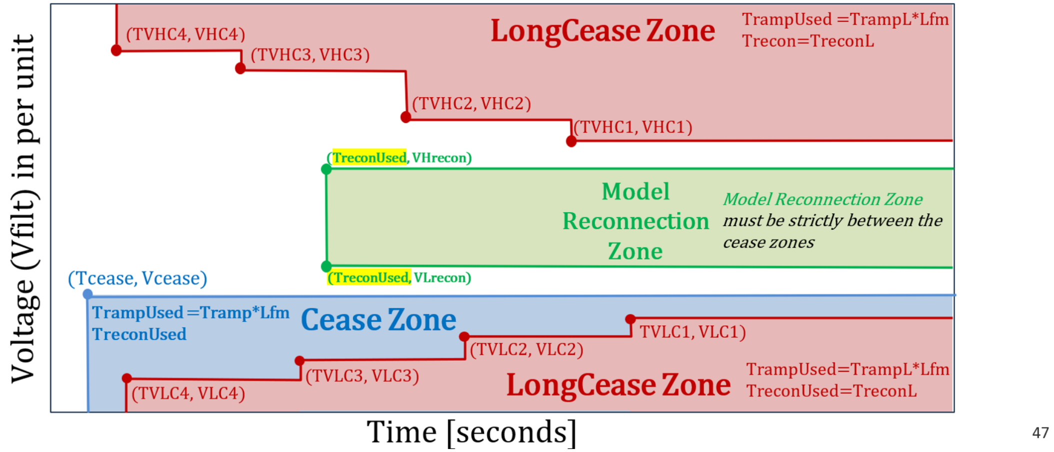
PERC2 Additions
Adding High/Low Frequency Tripping, Imax

- Total Current Limit: Imax
  - For modeling a UPS, the MvarInit is typically 0.0 and no Mvar response is modeled, so this isn't needed for those.
  - Added for completeness.



PERC2 Changes
Cease and Long Cease Zones

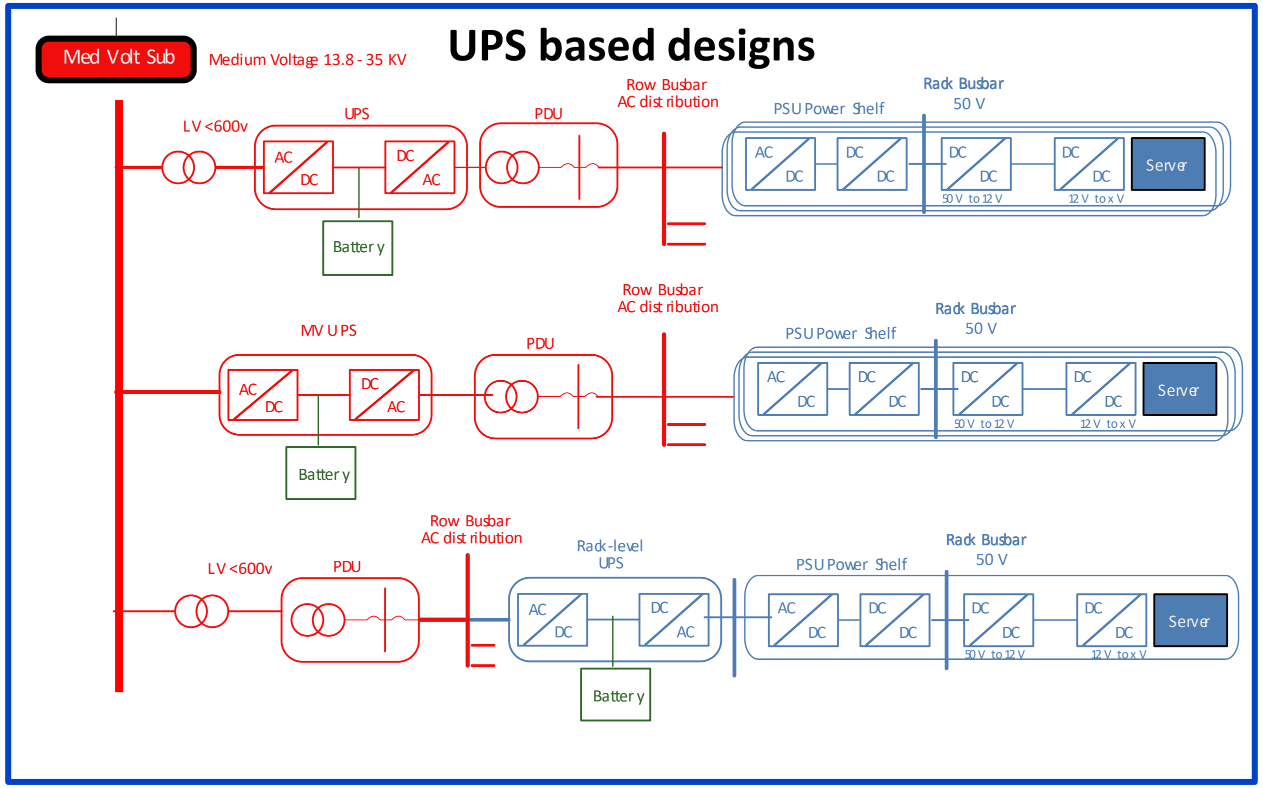
- "Blue Zone" and "Red Zone"



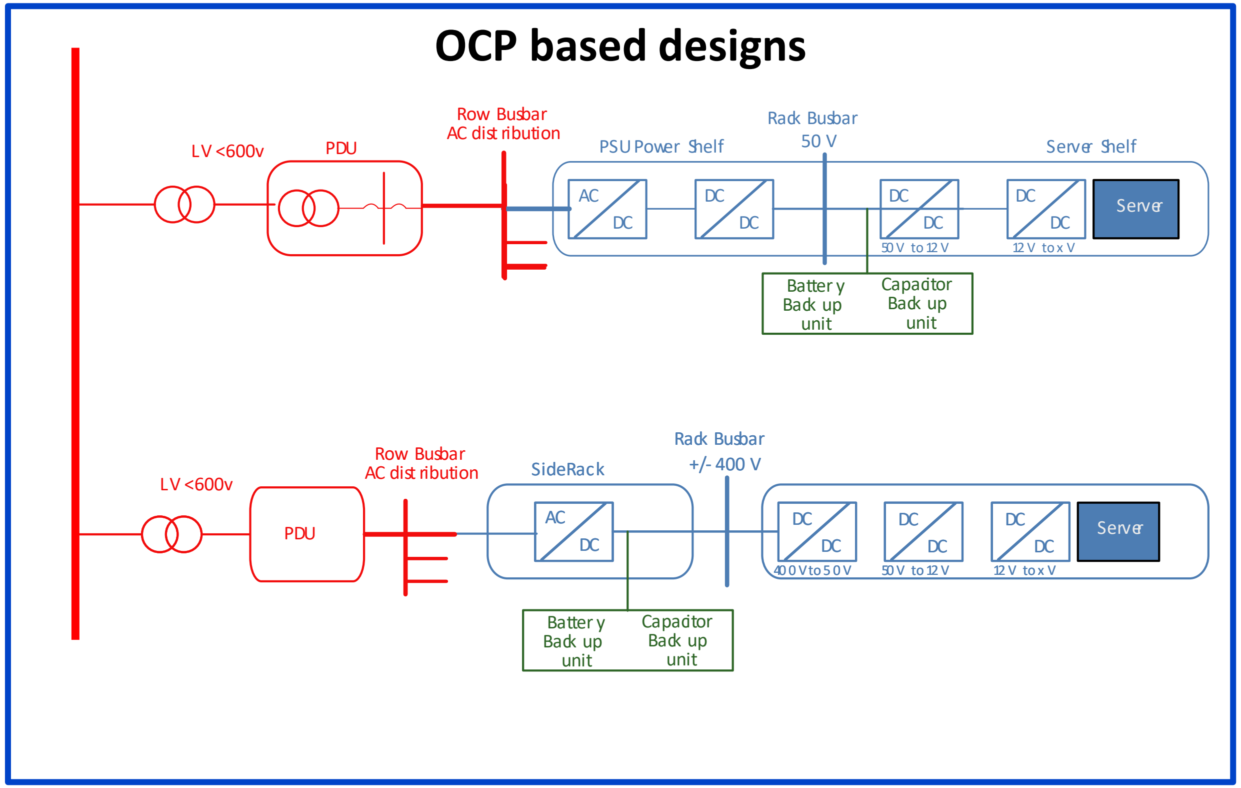
- ☐ PERC1 model got officially released in 2025. Powerworld, PSLF and PSS®E (36+) has it. **PSS®E 34/35 users, contact to get a DLL. Same model (coded by Kannan S and Benchmarked) in a DLL format is available.**
- ☐ Some improvements needed to the model structure to include:
  - ▪ More flexibility to model ride-through curves
  - ▪ Momentary cessation implementation
- ☐ Application guide in the works in conjunction with NERC to provide examples on model creation

Modeling Novel Data Center Architectures

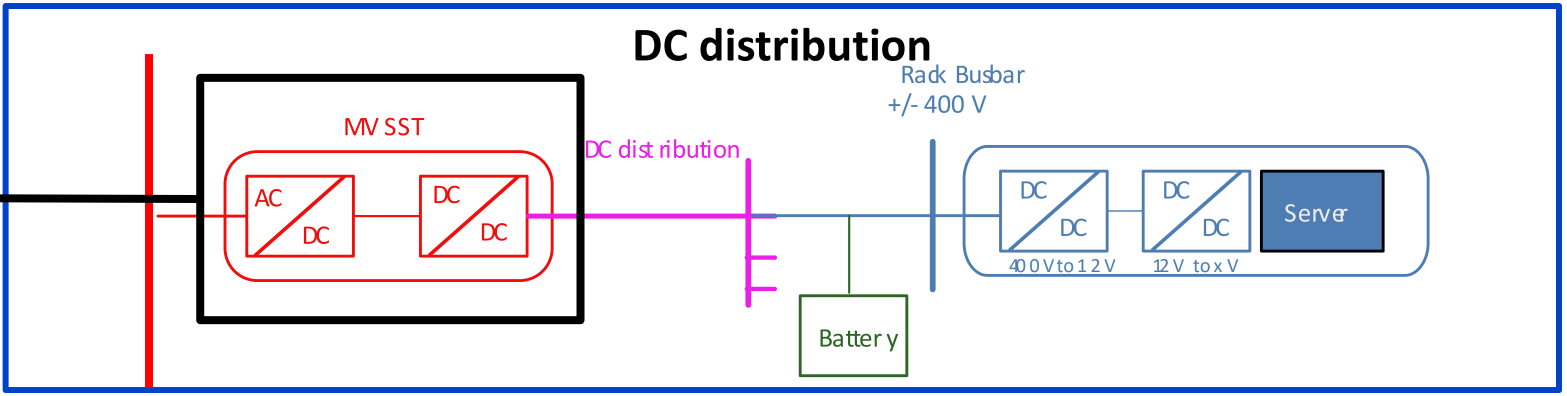
UPS based designs



OCP based designs



DC distribution



Model of 3 phase Solid-State Transformers

(In development)

Key Topics being Addressed

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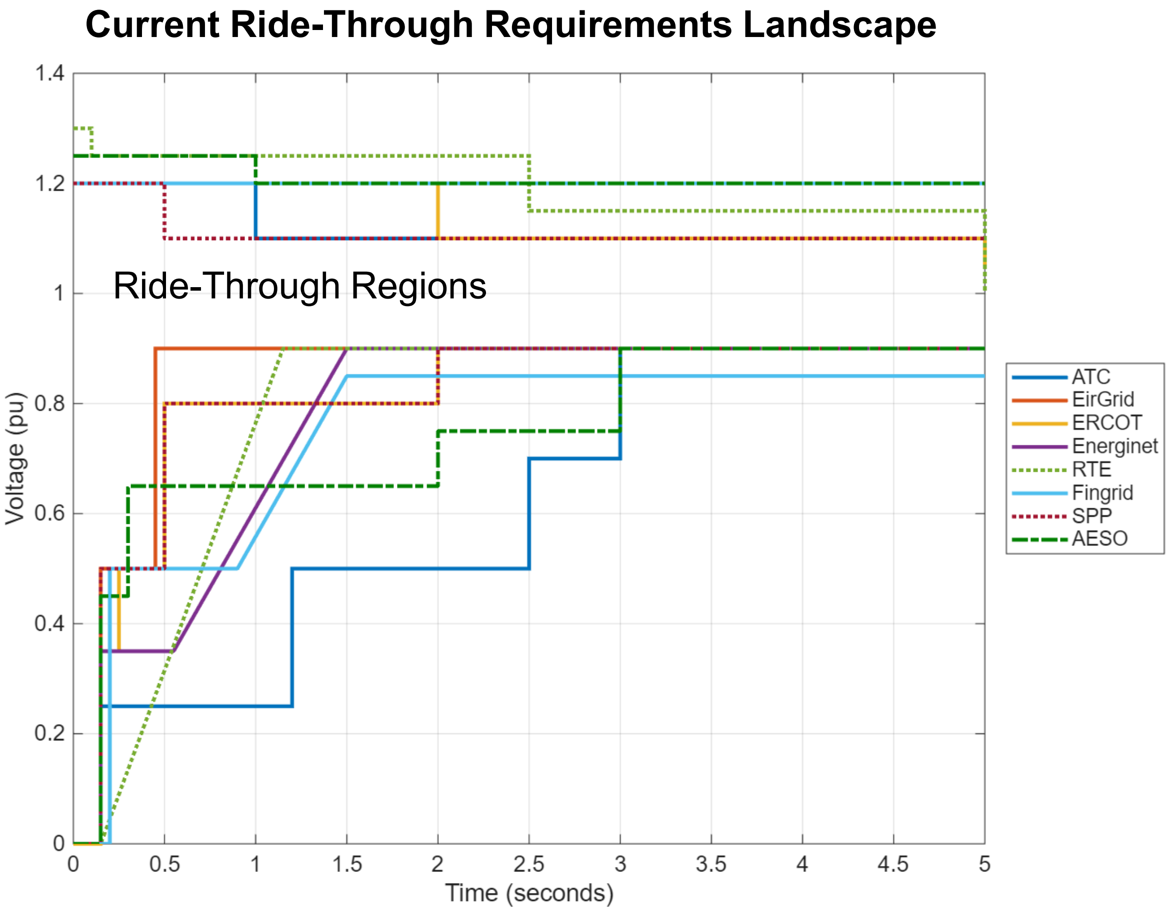
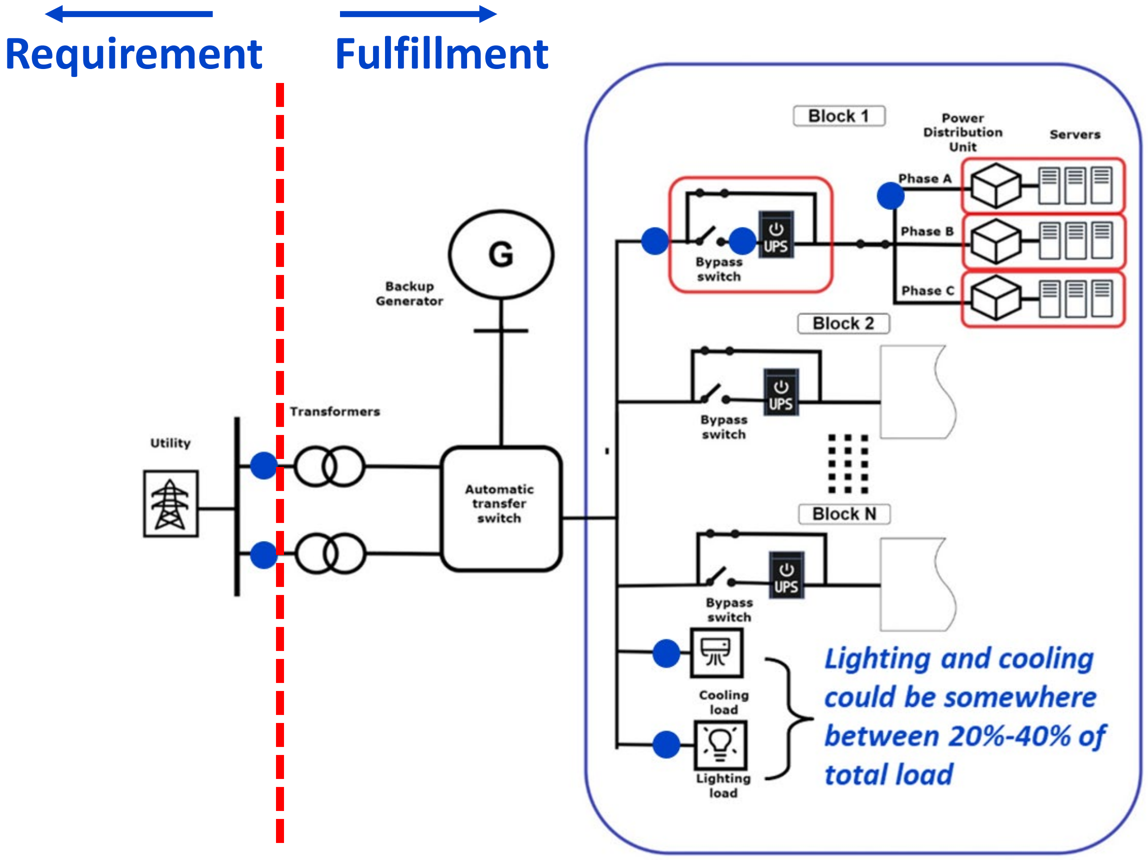
04 Interconnection Studies for Flexible Loads

Challenges with Ride-Through





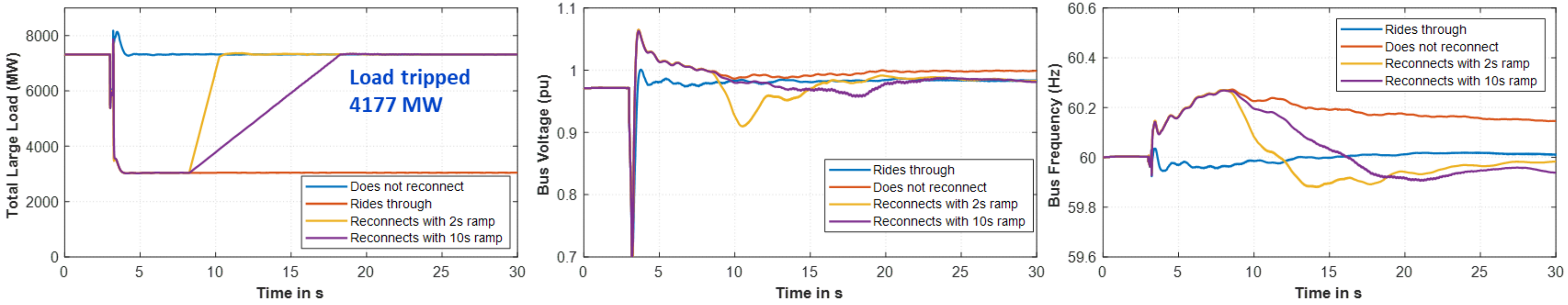
Lighting and cooling could be somewhere between 20%-40% of total load

- Overall industry desire to have a uniform RT standard
- NERC LLWG WP suggests using ERCOT NOGRR282 as the starting point

- RT standards will be applicable at the POI but met by performance of devices behind a distribution network
- Need a method for compliance demonstration

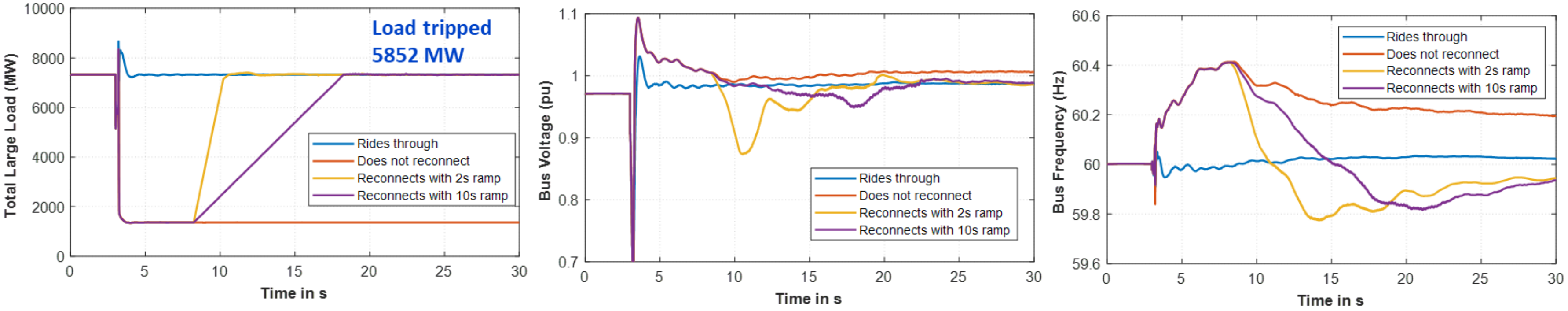
Defining VRT/FRT Curves for Interconnection

Synchronous Machines



Load tripped
4177 MW

IBR case



Load tripped
5852 MW

- Testing if existing VRT characteristics work for a utility's system
  - Low load conditions and High load conditions need to be studied separately
  - Identifying if certain load pockets require a deviation from uniform characteristics

Equipment Testing and Model Validation

- ☐ Ride-through requirements are one of the key reliability needs being discussed in the industry today
- ☐ Independent testing and conformity assessment are two industry needs
- ☐ ***What are we planning to do in this space?***
  - **Devices of Interest** – Data Center Grid Interfacing Equipment
  - **Testing Outcome– Independent Performance Verification**, **Conformity Assessment with Grid Code, Model Verification and Validation**
- ☐ ***What is our desired outcome?***
  - **Development of a testing protocol** that can be used to demonstrate conformity as well as aid model verification and validation
  - **Develop a complete process that maps** equipment testing to facility level conformity assessment with clear documentation that can be used for submission during interconnection
  - **Provide insights** to stakeholders via independent testing and demonstration

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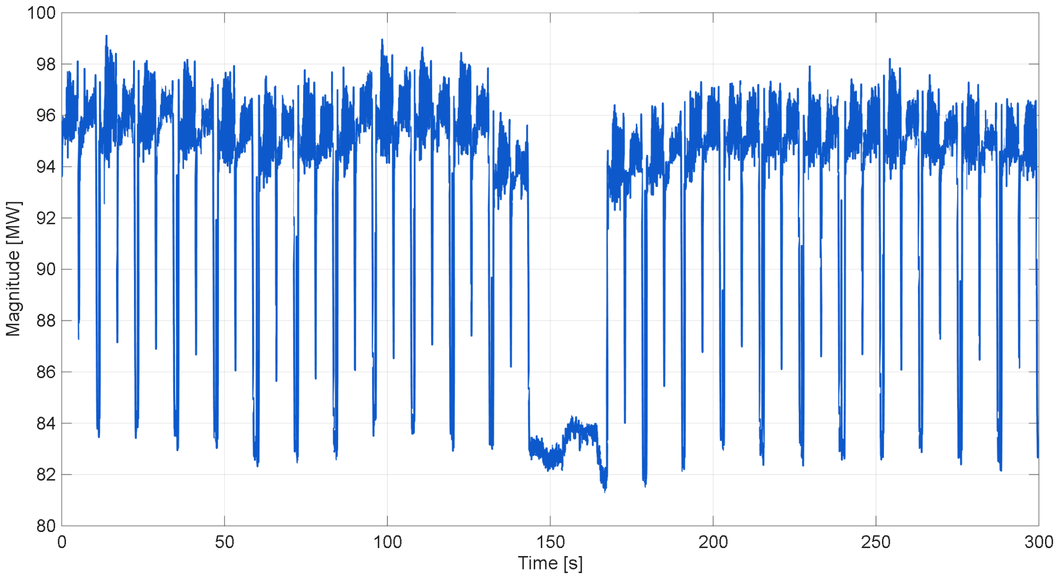
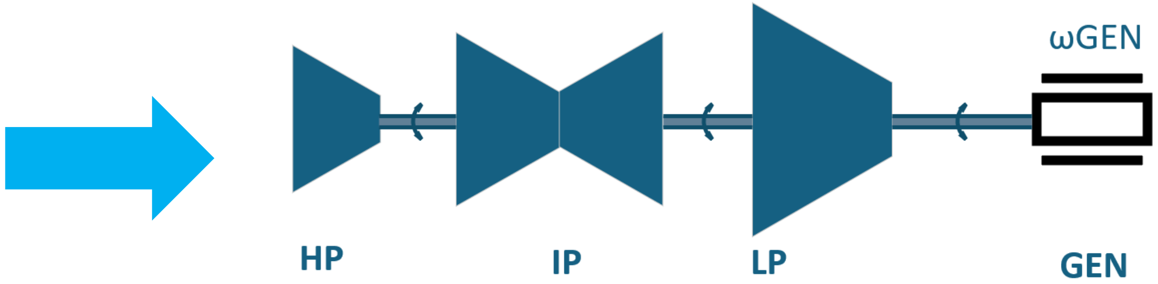
Why AI loads are a concern for generators?



Data Center Load with AI Training



Steam turbine Multi-Mass Model

- Training LLMs require solving large linear equations periodically. These periodic operations causes load spikes followed by lulls.
- Load pulsations can range between 0.1 Hz – 55 Hz with the prevalent ranges between 5 – 55 Hz
- Any pulsating load will cause pulsating torque to appear on a nearby generators shaft and associated assembly
- ***Beyond a certain limit, this can damage the equipment***

How does the utility engineer address this challenge?

Pre-interconnection

- **Identify tolerance limits** for generators (**EPRI reports and SMEs**)
- Map generator limits to injection limits at data center site (**PSS®E/PSLF**)
- **Set limitations for data center** site as a part of interconnection requirements

Phasor models sufficient

Interconnection Phase

- Identify load shape from data center (**work with customer**)
- Study the impact on nearby generator (**EMT, multi-mass modeling**)
- **Design mitigation measures** in coordination with data center customer

EMT analysis only for mitigation or detail assessment

Post - Interconnection

- Monitoring and Protection

Understanding Machine Limits

- What is tolerable for a synchronous machine?

Non-Resonant Frequencies	Resonant Frequencies
Peak – Peak < 10% of Machine MVA	Avoid Entirely

Above 10% is problematic based on assessment with available data. Actual tolerance limit could be much lower than 10%. Talk to your GO and OEM.

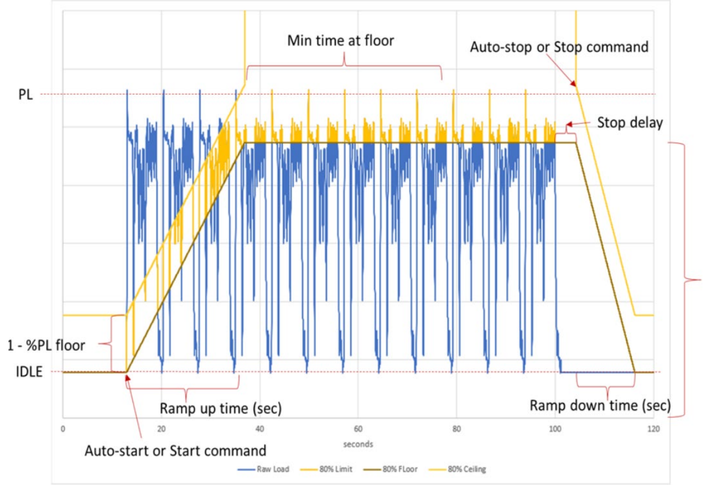
- How do we do these assessments?

Defining Limits	Detailed Assessments
PSS®E/PSLF/PW/DSATools can be used to define injection limits	Multi-mass model – work with your OEM Data Center – Current/Power injection model with load shape knowledge sufficient

Mitigation Methods

ESTATCOM	BESS GFM	BESS GFL	Double Conversion UPS
Good at mitigating high frequency oscillations but **may fall short at preventing lower frequency** oscillations	**May not be the most suitable option** when sited closer to a generating plant and high SCR.	**Better performance than GFM** but control delays (Pref change can **reduce effectiveness at high frequencies**	Good performance for high frequency oscillations but may fall short on **lower frequency oscillations unless storage sized appropriately**

Upcoming Rack Level Solutions



Mitigation requires low latency and controlled injections. RATHER THAN GFM/GFL, LOOK FOR PERFORMANCE

Evaluation in progress

1. Understanding the advantages and disadvantages of different control methods (OEM agnostic)
2. Understanding how siting of mitigation can affect sizing
3. Understanding if certain mitigation methods can provide multiple benefits

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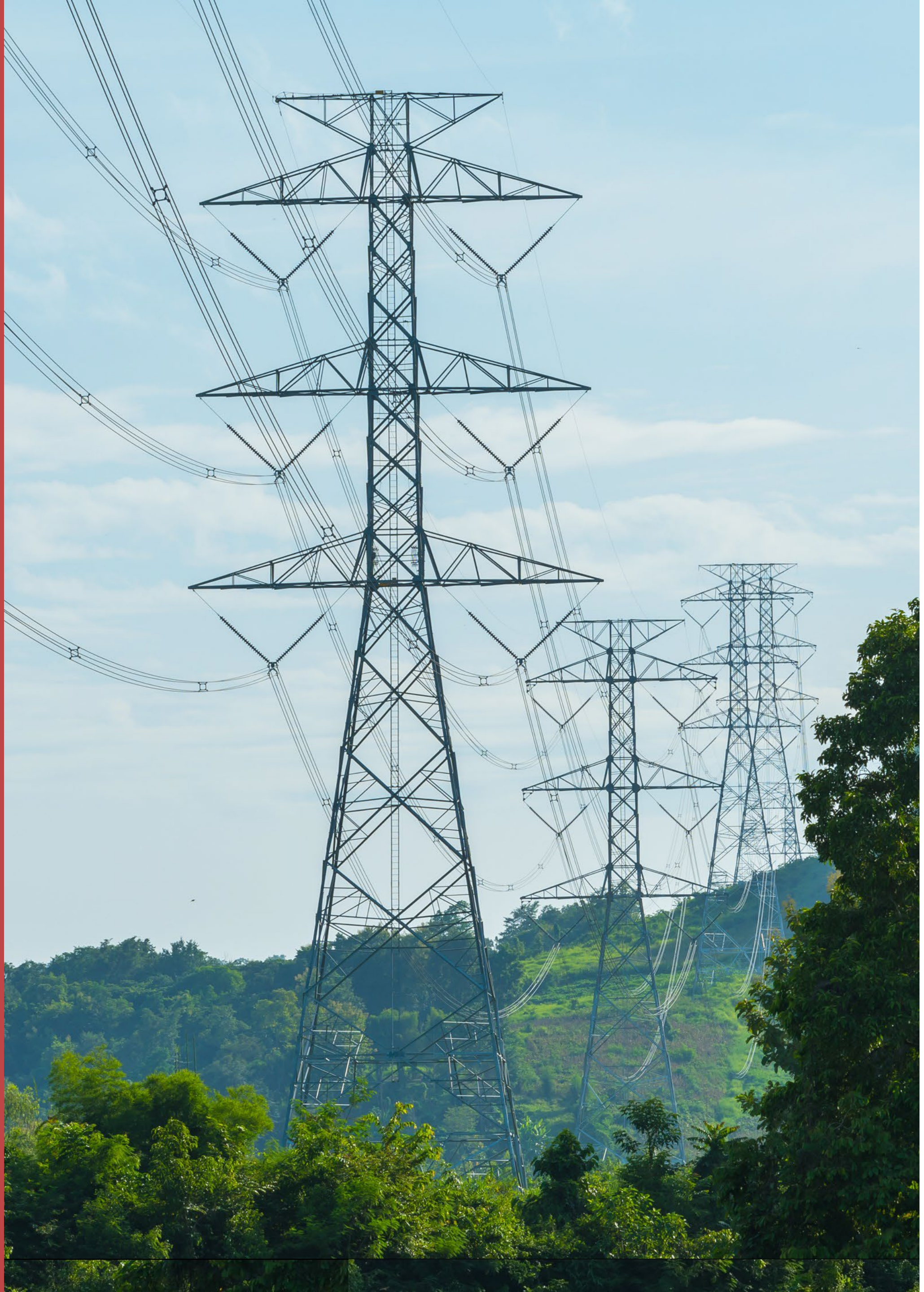
Interconnection Assessments for Flexible Loads

- Many utilities as a practice treat load as fully firm for interconnection studies.
  - Some entities (e.g., ERCOT) has presented methods to treat provisional controllable load resources differently in interconnection studies.
- Flexibility offered by load may not be fully considered during interconnection, especially when transmission overloads or voltage concerns exist.
- Ensuring that flexibility treatment during planning can be translated to real-time operations is important
  - If planning studies are significantly different from real-time operational reality, this can present a challenge for operators
- Interconnection studies would need to evolve including assessments of multiple scenarios and possibly multi-snapshot assessments to ensure value of flexibility can be leveraged without compromising reliability.

Work in progress with a few use-cases. Findings can be insightful for others looking to evaluate flexible loads

TOGETHER...
SHAPING THE FUTURE OF ENERGY®



Thank You for Attending

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