Large Load Forecasting for Operational Outage Scheduling

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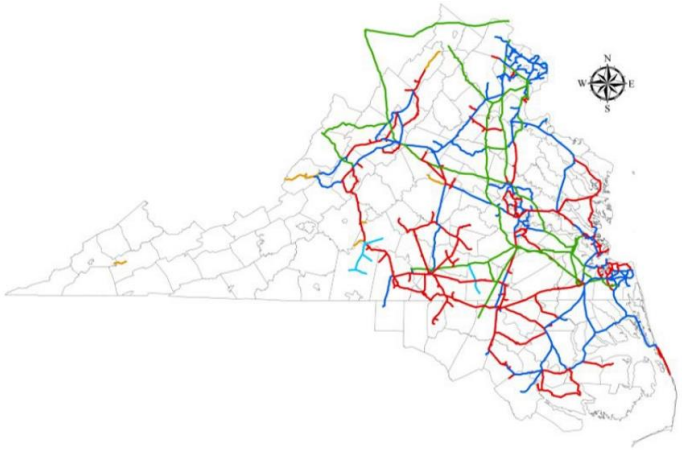
Dominion Energy Transmission Footprint

Service Territory: Virginia, North Carolina, West Virginia



Transmission System Overview

- 6,800 miles of transmission lines, broken down by voltage level:
  - 500 kV — 1,315 miles
  - 230 kV — 2,979 miles
  - 138 kV — 64 miles
  - 115 kV — 2,309 miles
  - 69 kV — 78 miles

- Substation & Infrastructure Assets
  - 1,000+ substations
  - ~50,000 transmission structures

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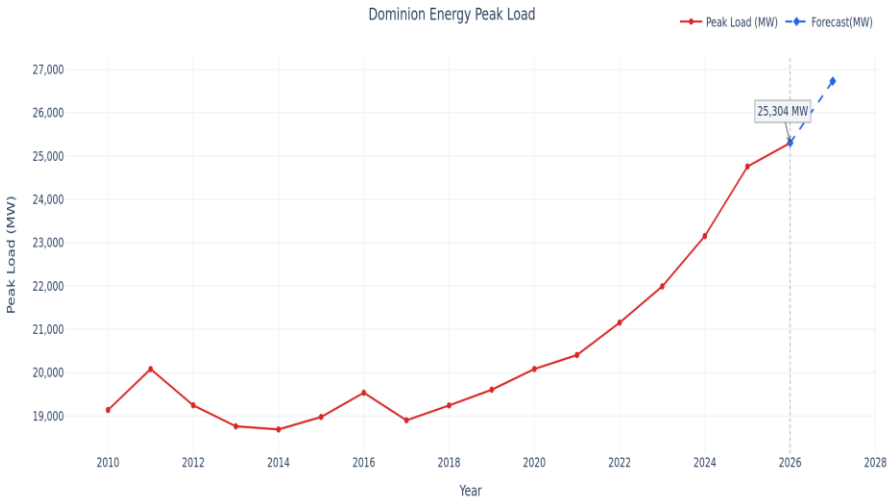
Dominion Energy – Large Load Growth

Large-Load Queue: ~70 GW of large-load requests.

- ~25 GW already assigned projected connection dates through 2031.
- ~45 GW batched and under active study for future connection dates.

Dominion Energy continues to receive:

- ~10 new large-load DP requests per month, representing 2–3 GW of additional requested load every month.



Why This Matters : Total requested load is nearly 3× Dominion Zone's historic system peak.

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Transmission Forecasting

Not All Forecasts are Built the Same. Nor Should They.

System Operations and PJM Operations

- Require increasingly precise outage and capacity planning.
- A narrowing margin between load and capacity — especially in shoulder months — demands more explainable, decision-ready forecasts.

Changing Planning Reality (ET Planning)

- Time horizons, service areas, and business objectives are diverging rapidly.
- Transmission planning can no longer rely on historically over-engineered grid assumptions.

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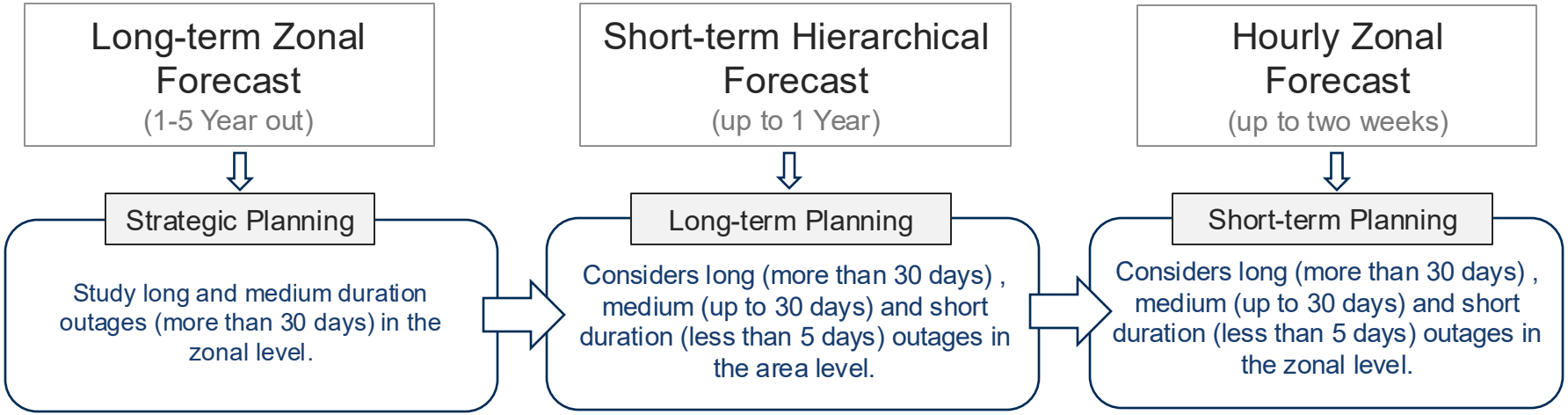
From Forecasts to Operations Outage Planning



Goal – Scheduling as many outages as possible subject to maintaining system reliability

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Long-term Zonal Forecast for Strategic Planning

Focus

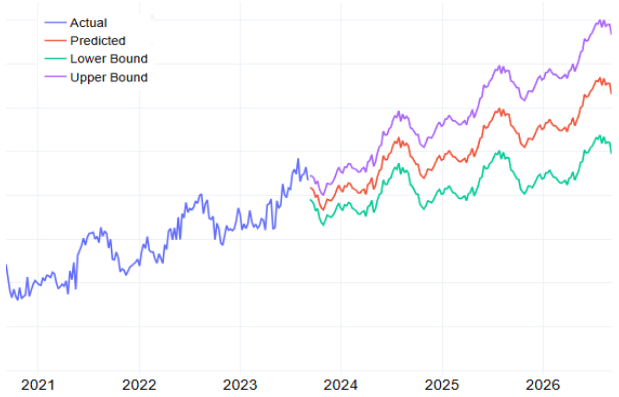
Study outages long and medium duration (more than 30 days) in the zonal level. PJM approval for longer duration projects

Types of outages considered

500 KV reliability projects, RTEP projects, Line and substation upgrades

Scheduling Strategy

- Considering probabilistic load forecasts for identifying the window for each high priority outages in each season.
- If conflict (thermal, voltage violations) occurs, then try to reschedule the outage in the off-peak seasons.



Study Details

Monthly outage scheduling studies are performed and optimized to accommodate as many as high priority outages possible subject to system reliability

Tools used: PSSE/TARA, ANODE (Analysis on Demand)

Challenges: Can't accommodate area-level studies

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Short-term Hierarchical Forecast for Outage Planning

Focus

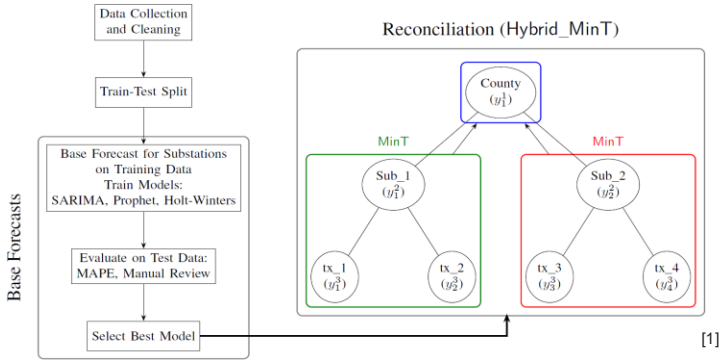
Considers rescheduling short and medium duration (up to 30 days) outages in the area level.

Types of outages considered

Every outage in the system including maintenance outages, breaker profiling

Scheduling Strategy

- Rescheduling the outages if conflict occurs.
- Planning outages in the data center alley in winter season with PJM approval.
- If rescheduling doesn't work, then switching solution is studied using substation level and area level hierarchical forecast.
- Load loss and islanding scenarios studied.



[1]

Study Details

Time snapshot outage scheduling studies based on substation level coincidental peak loads are performed and optimized to accommodate as many as high priority outages possible subject to system reliability

Tools used: EMS State Estimator

Challenges: Can't accommodate uncertainty with future assets

[1] S. S. Ghosh, B. Luthra, J. De La Ree, K. D. Jones, "Hierarchical Forecasting for Data Center Loads", accepted at IEEE T&D 2026

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Hourly Zonal Forecast for Near Real-time Outage Planning

Focus

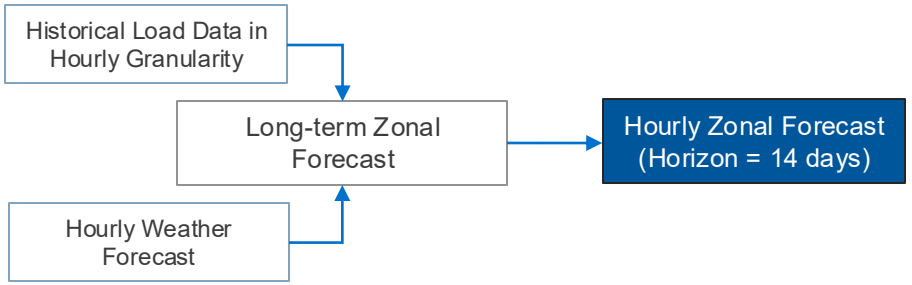
Considers rescheduling short duration (less than 5 days) outages in the system level.

Types of outages considered

Every outage in the system including maintenance outages, breaker profiling

Scheduling Strategy

- Accommodate near real-time weather forecast for obtaining final decisions about outage rescheduling.
- Prioritize rescheduling outages of short duration.
- For conforming loads in the system, if some violations occur, it is rescheduled to off peak days.
- For critical projects, RAP criteria is evaluated.
- Communicate the final decision with PJM.



Study Details

Time snapshot outage scheduling studies based on system level coincidental peak loads are performed and optimized to accommodate as many as high priority outages possible subject to system reliability. Final Decision for approving outages in near real-time.

Tools used: EMS State Estimator

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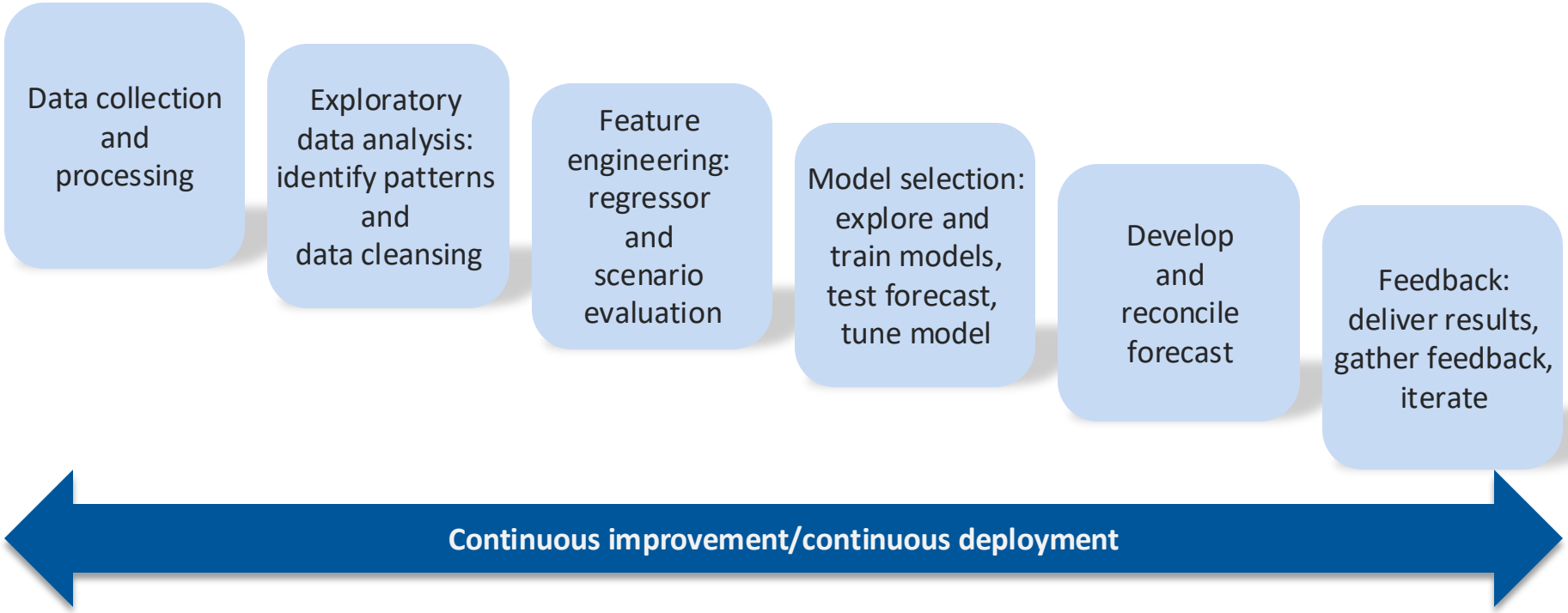
Forecasting Framework



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Identification of Large Load Profiles : A Transformer Level Analysis

[2] S. S. Ghosh, B. Luthra, J. De La Ree, K. D. Jones, “Non-Conforming Load Pattern Analysis”, accepted at IEEE General Meeting 2026

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Understanding conforming vs non-conforming load patterns

Hyperscalers

Massive facilities (>100 MW) providing cloud services. Likely steady, high-load operations running 24/7.

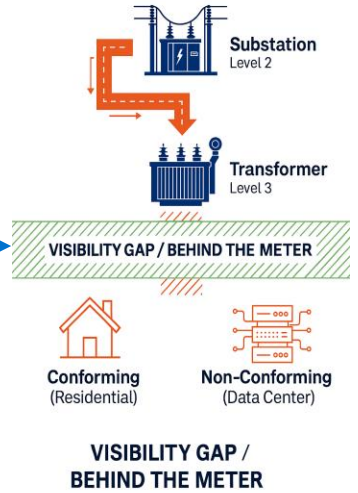
Colocation

Shared facilities housing multiple tenants. Likely erratic, “spiky” behavior dependent on various clients.

Enterprise

Private, single-company centers. Usage varies by internal business cycles and specific needs.

Is this load a residential or data center or COOP? Without visibility, forecasting is difficult.



VISIBILITY GAP / BEHIND THE METER

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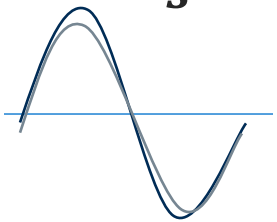
Defining Three Core Principles

Features:

- ***Shape:*** Aggregates raw load measurements into H hourly means over the observation window.
- ***Daily range:*** Computed as the mean daily range, defined as (daily maximum load – daily minimum load) over D days.
- ***Daily variance:*** Represents the average daily variance across the observation window.

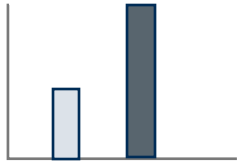
x_s



SHAPE

Weight : 0.3
Dimension : 48

x_r



RANGE

Weight : 8
Dimension : 1

x_v

VARIANCE

Weight : 8
Dimension : 1

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Interpreting Load Profiles from Agglomerative Clustering

Type 1: Residential and commercial signatures:

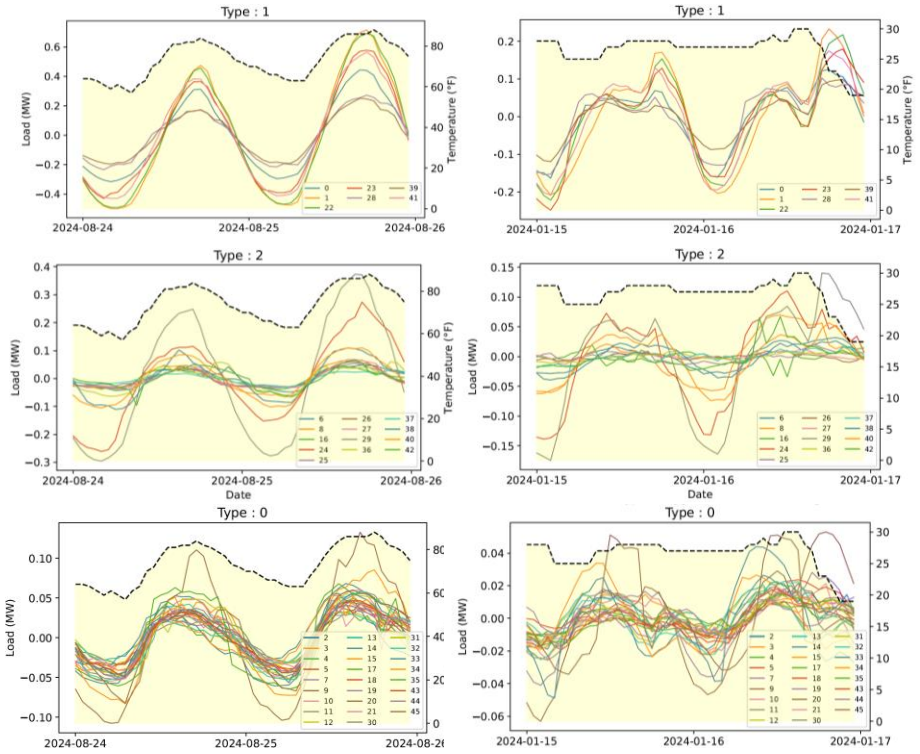
- Highest mean daily load range with regular, periodic patterns.
- Strong alignment between daily peak load and peak ambient temperature.

Type 2: Hyperscaler data centers:

- Lowest average daily range, with flat and stable profiles.
- Characterized by continuous, high-capacity power draw (often >100 MW).

Type 0: Edge and colocation data centers:

- Highly irregular and spiky load profiles.
- Daily variance like Type 2 but with peaks that often occur between 12 p.m. and 6 p.m., making timing unpredictable.



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Characterization of Conforming vs. Non-conforming Load Archetypes

Archetype	Category	Range (Average)	Variance (Average)	Temperature Corr. (Summer)	Profile Characteristics
Type 1	Conforming	13.44	7.39	0.96	High range/variance; driven by residential cooling and human activity.
Type 2	Non-conforming	2.47	1.32	0.90	Hyperscaler; extremely flat, stable, draws >100 MW.
Type 0	Non-conforming	3.45	1.84	0.91	Edge/Colocation; unpredictable peaks, often between 12 PM–6 PM.

Archetype	Category	Range (Average)	Variance (Average)	Temperature Corr. (Winter)	Profile Characteristics
Type 1	Conforming	6.29	3.01	-0.27	In winter, lower temperature increases power consumption due to residential heating.
Type 2	Non-conforming	1.31	0.67	-0.007	Hyperscalers ; not affected by temperature almost constant load.
Type 0	Non-conforming	1.23	0.63	0.05	Edge/Colocation; similar large load characteristics, slightly low range.

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From Blind Spots to Precision Decisions

This framework ensures the electrical signature of each customer becomes an intelligent signal

Engineered load-shape features strengthen forecasts:

- Adding quantitative features—daily range, variance, peak timing, intra-day stability—helps forecasting models learn how each transformer behaves, not just what its past values were.
- Reliable forecasts for new assets with little or no history.

New asset integration: Predicts load behavior for **newly commissioned transformers** lacking historical data.

- Early “electrical signatures” are matched to learned archetypes (Type 0/1/2/3) to whether the customer is likely residential, hyperscale, colocation, or enterprise.
- Provides explainable features vital for planning, forecasting, and regulatory communication.
- Enhances reliability under heavily constrained substation and transmission conditions.

This study on data center load pattern analysis is pivotal as a decision-support resource for load forecasting, planning, and operational reliability.

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Thank You

Questions? Get in touch!

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