

GRID EMT

SIMULATION INITIATIVE

Large Load Models & Disturbance Challenges Observed

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Key Regulatory Bodies



FERC – Exclusive jurisdiction to determine and regulate the reliability of the electric transmission grid



NERC – Regulatory authority to develop and enforce the mandatory reliability standards – criteria, data and methodology to evaluate and ensure the reliability of the bulk power system in North America



PJM – Regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of 13 states and the District of Columbia; Virginia law mandates Dominion Energy's membership



SCC – Regulates Virginia public utility facilities, retail rates and service including transmission line need and routing; issues certificates of public convenience and necessity (typically electric transmission lines equal to or greater than 138 kV)

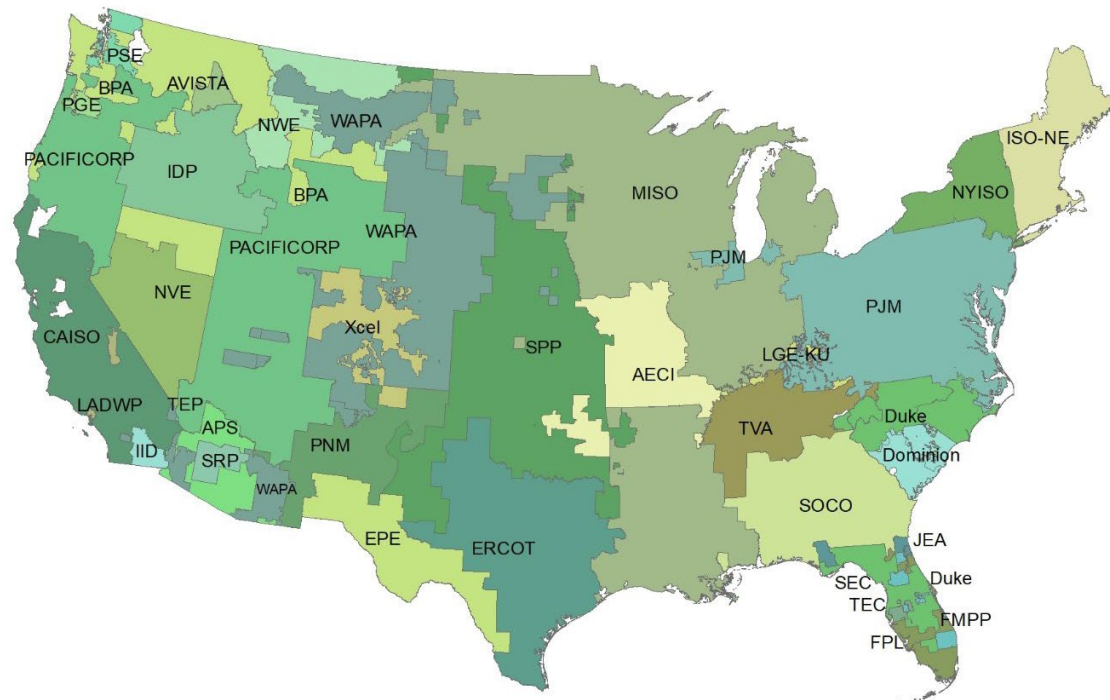
**Cities
and Counties**

Local Governments – Regulate local land use (substations); typically electric transmission lines equal to or less than 138 kV



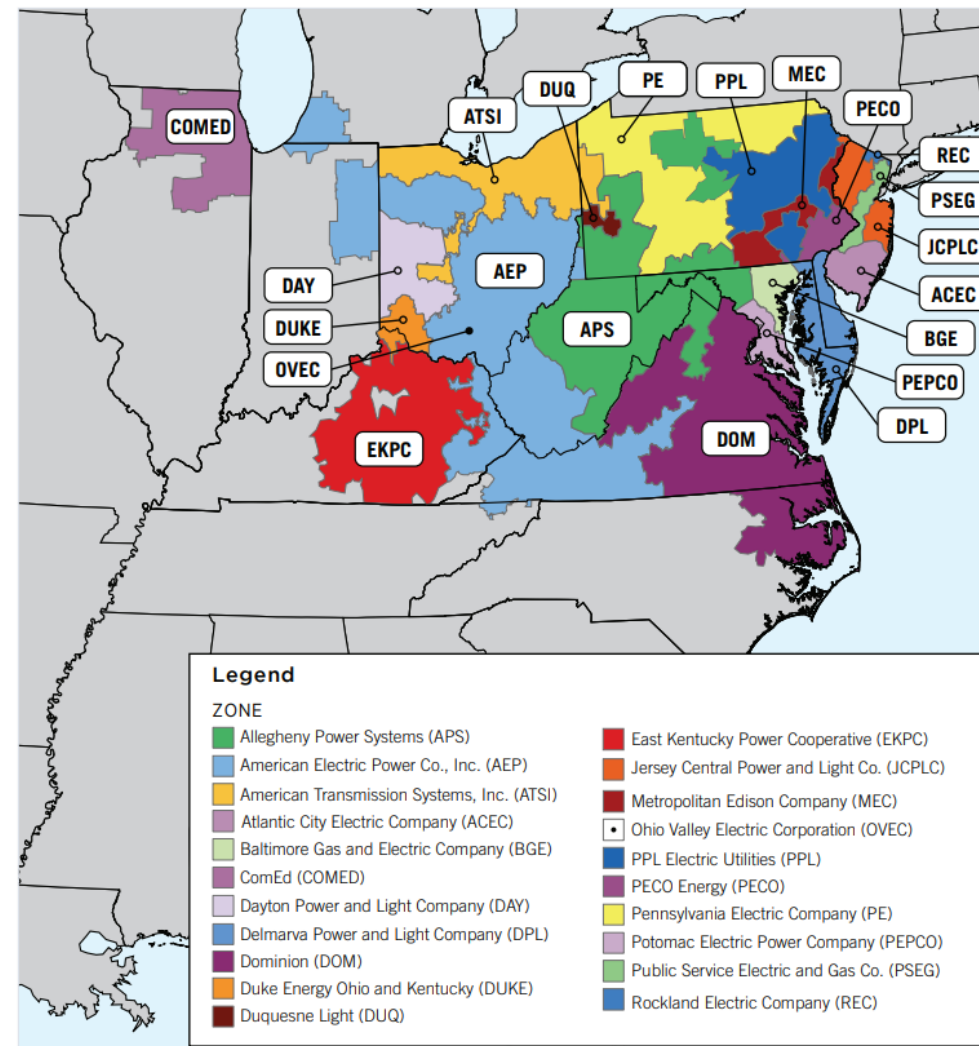
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Dominion Energy in PJM



PJM

Pennsylvania New Jersey Maryland Interconnection LLC
(Mid-Atlantic region power pool).

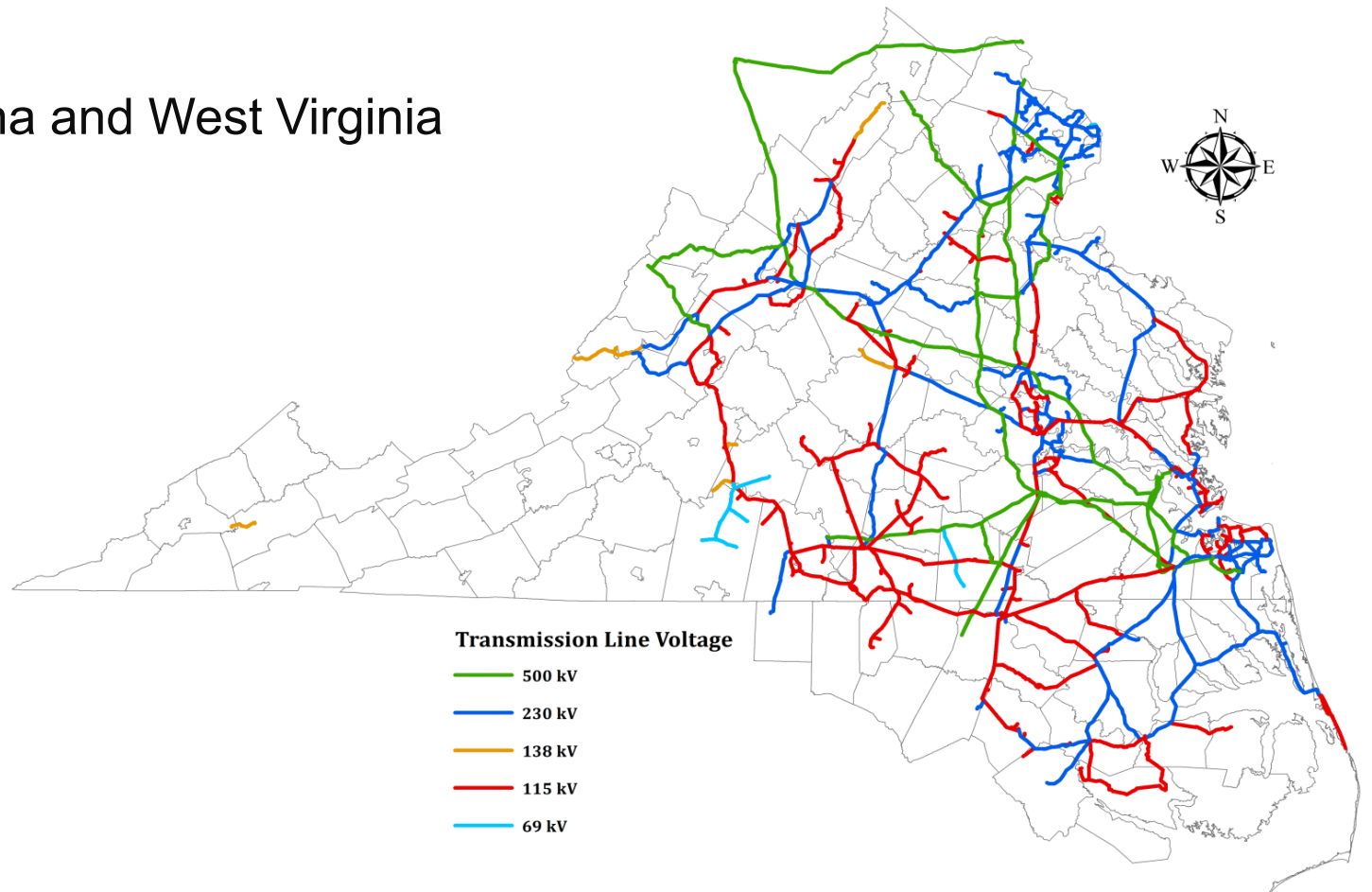


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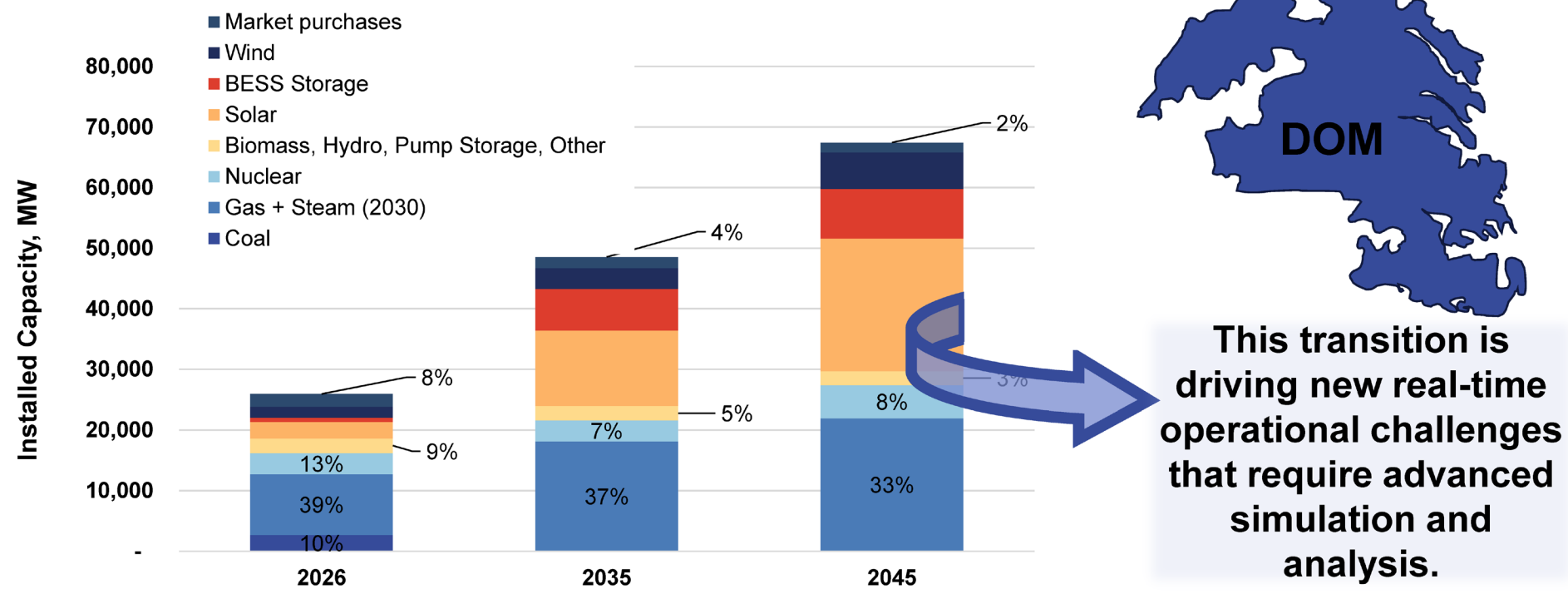
Dominion Energy Virginia ET at a Glance

- \$7.8 billion assets in service
- Operates in Virginia, North Carolina and West Virginia
- 6,800 miles of transmission lines
 - **500 kV** – 1,300 miles
 - **230 kV** – 2,927 miles
 - **138 kV** – 64 miles
 - **115 kV** – 2,311 miles
 - **69 kV** – 78 miles
- More than 900 substations
- ~50,000 transmission structures



Dominion Energy System Overview Generation Portfolio Transition

Increase in Renewable-based Resources

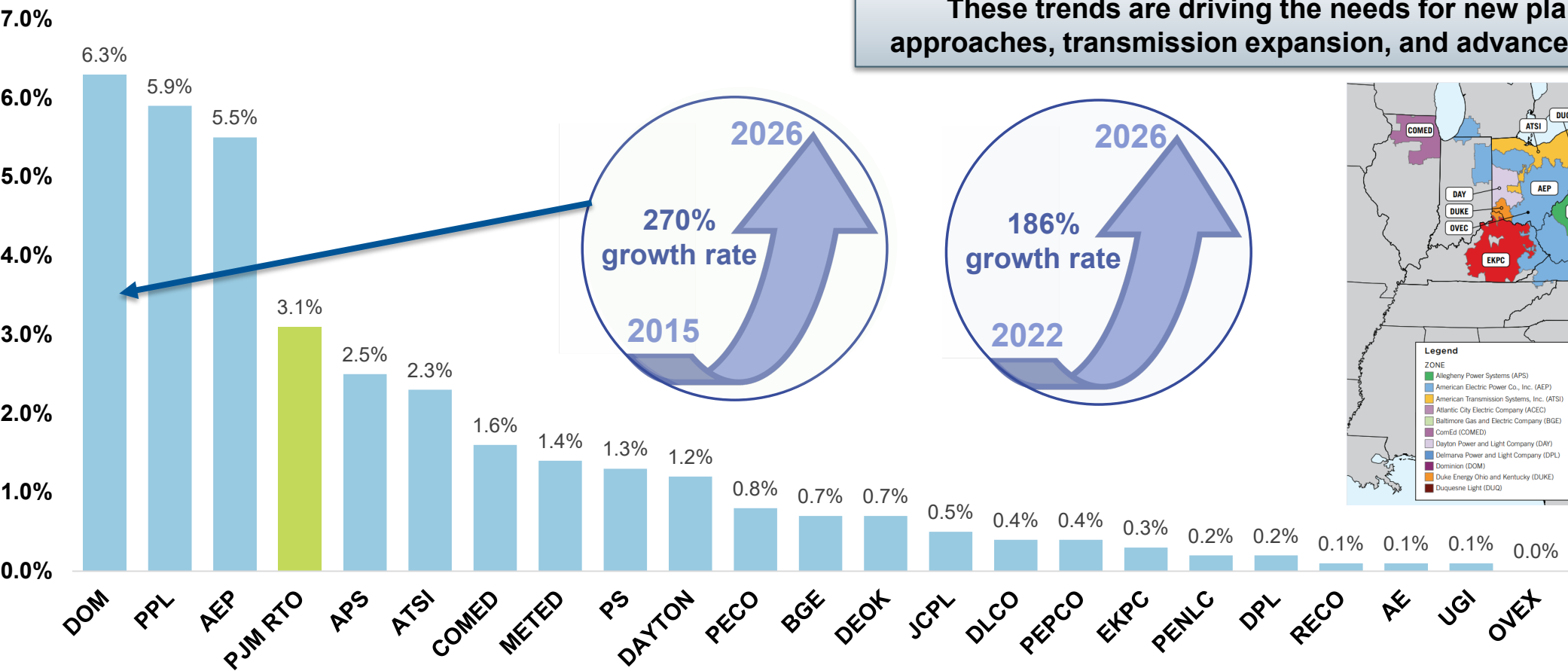


Source: [2025 VA/NC Integrated Resource Plan Update](#), adapted from Table 5.1.1.1 and Figure 5.1.1.3

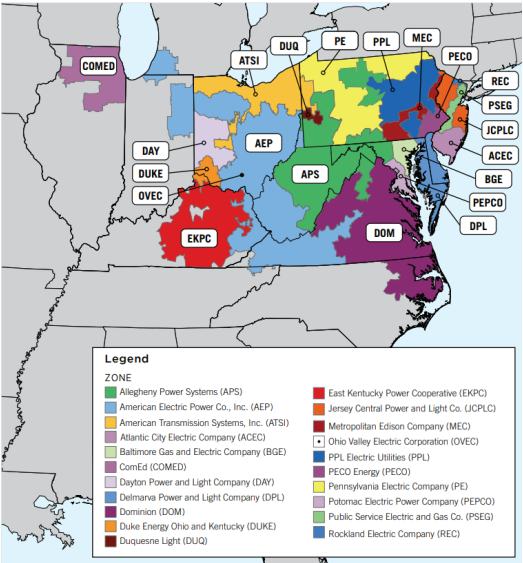


Dominion Energy System Overview Load Growth

These trends are driving the needs for new planning approaches, transmission expansion, and advanced studies.



PJM Yearly Summer Peak Load Growth Rate (2026 - 2036)



Scope for EMT Test Cases for Large Load Interconnection

EMT representation is needed when power-electronic control interactions, unbalanced faults, or sub-cycle transient behavior cannot be accurately captured in positive-sequence phasor simulation.

Balanced and unbalanced faults: 3-ph, 1LG, 2LG faults at POI and on transmission system within 2-3 substation; verify ride through and post-fault recovery.

Voltage step disturbance: LVRT and HVRT step tests to confirm boundary behavior such as current limiting scenarios.

Frequency step disturbances: Under and over frequency events; verify FRT performance across full envelope.

Weak-grid sensitivity: Vary Thevenin equivalent SCR from strong to weak; test control instability or oscillatory growth.

Post-disturbance recovery: Post-fault Active Power Recovery (PFAPR) ramp verification.

SSCI / SSTI with nearby generators: Load cycling simulation (>10 Hz) to test excitation of generator modes.



Ride Through Modeling and Study Definition

- ❑ Define a set of contingencies, historical information can be used to determine critical contingencies.
 - Generation loss (Severe voltage drop),
 - Three phase short-circuit,
 - Unbalanced fault (We need sequence data, probably not possible),
 - Busbar faults,
 - Breaker failure (Probably the largest one),
 - Loss of reactive support.
- ❑ Zonal analysis (Planning zones)
 - Worst-case voltage sag and swell per zone,
 - Worst-case voltage sag and swell generated by neighboring zones.
- ❑ Study origin: weakest bus per zone (largest voltage deviations)
 - Determine average deviation from weakest bus of respective zone,
 - Subsequent Analysis on worst case deviation from all zones with their respective weakest buses.



Considerations for Defining Protection Triggers and Times

- Relay operation + breaker operation + tolerance.
- Transmission line protection zones (Zones 1 and 2).
- Breaker failure (longest time).
- Any backup protection.
- Any RAS.

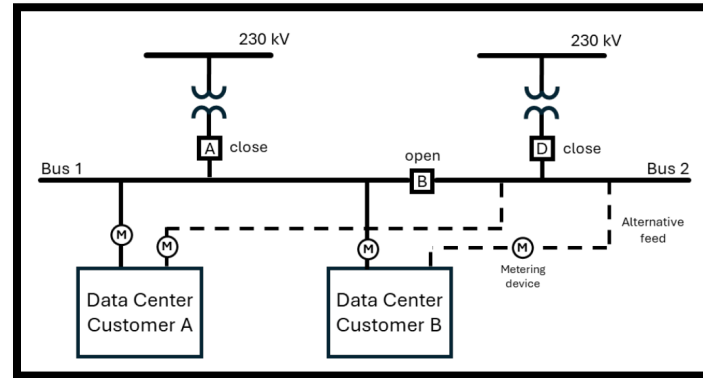
Step	Scenario	Why it's on the curve
1	Local SLG, 3PH primary protection clearing	Most frequent fault; everyday requirement
2	Local line fault cleared by backup protection relay	Primary relay fails; longer local clearing
3	Remote 3-phase, primary clearing	Depression propagating from neighboring zones
4	Remote 3-phase, Backup clearing	Depression propagating from neighboring zones
5	Remote 3-phase + breaker failure	Longest credible clearing — no cascade trip



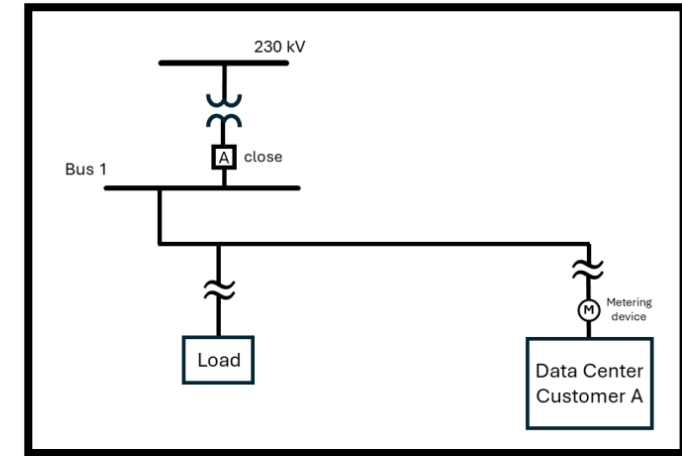
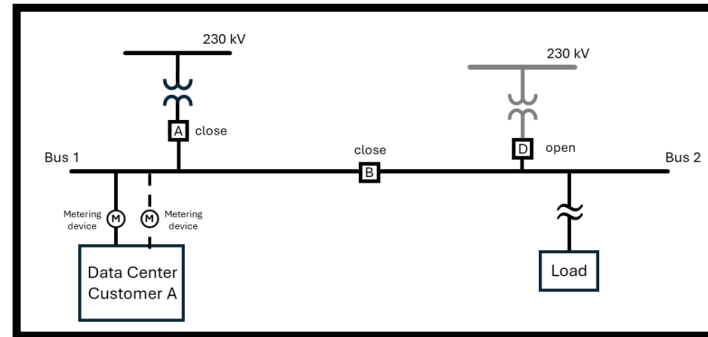
Modeling from Observability of Large Loads

- ❑ DEV ET network is fully observable with synchrophasor and/or digital fault recorder metering.
 - Transmission substation-level metering (high side, lines mainly).
 - Insufficient to determine individual data center response.

Alternate feeder scenario with multiple data center customers or data halls of campus.



Alternate feeder scenario with mixed loads



Common feeder scenario with mixed loads

Source: Dominion Energy Virginia, "Electric Transmission Facility Interconnection Requirements(FIR)", January 2026.



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Monitoring-based Performance Evaluations

- ❑ **Available data at the POI** (Point-on-wave measurement through waveform measurement units)
 - V,I waveforms 8 cycles (~0.13s) post-fault
 - V,I, RMS signals ~35s (5pre, 30post fault)

Limitations:

- RMS data provides magnitude only (no angle information), waveform window is too short for EMT playback simulation.
- Direct analytics of Data Center power profile in longer timescale is not feasible.

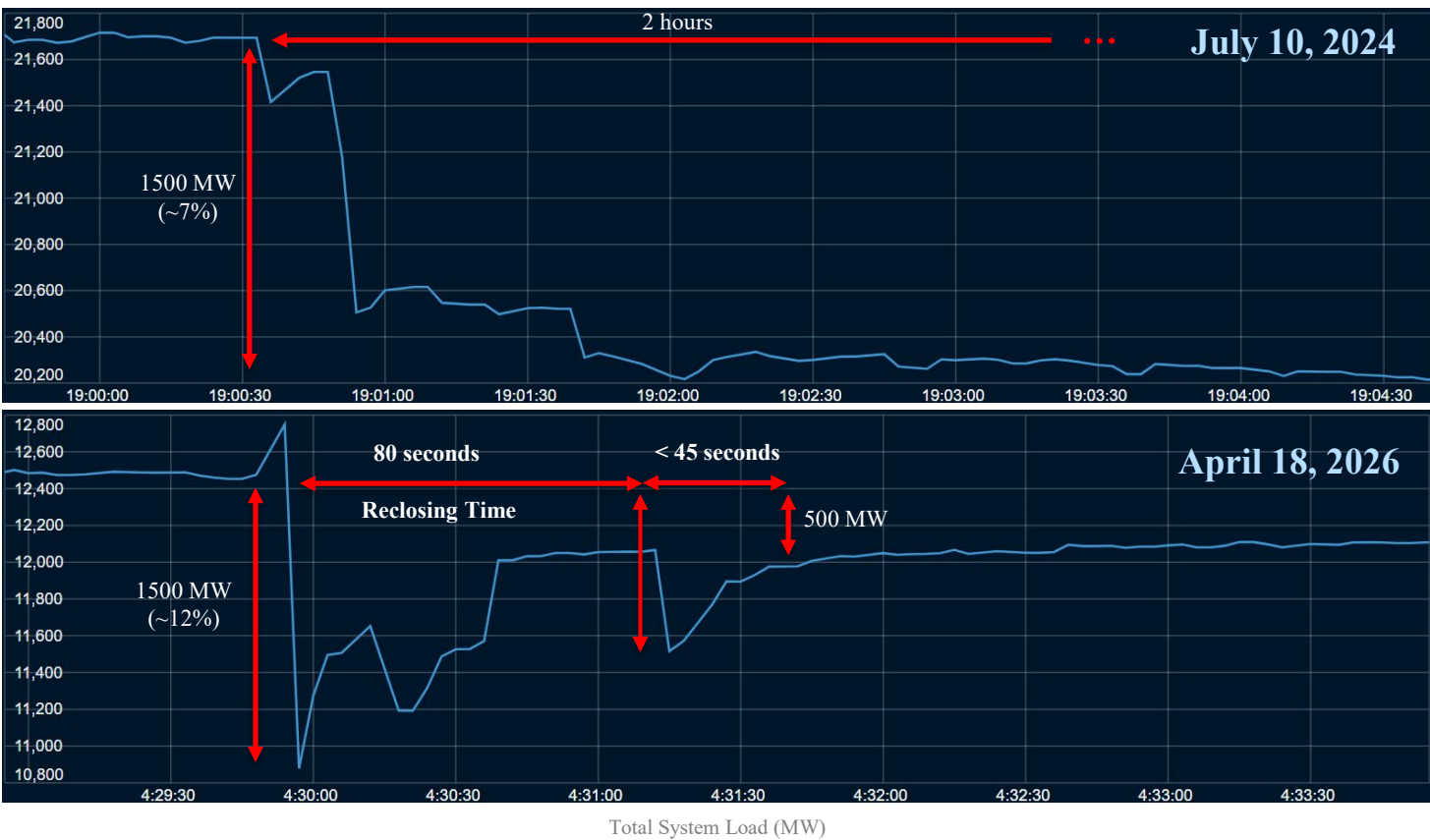
Approx solution:

- Identify largest voltage deviation dynamics from the event data and use it for worst case response analysis.
- Compare current envelope trends.
- Qualitative validation only (not point-by-point matching).



Monitored Transfer Events: Comparison of Large Load Loss

Parameters of Comparison	July 10, 2024	April 18, 2026
Initial Load response (MW)	1500	1500
Sustained Load Transfer (MW)	1500	500
Voltage Sags	6	6
Min V_Sag (%)	68.3	63.6
Max V_Sag duration (ms)	75	67
Sustained Transferred DC	11	1
Impacted Substations (Threshold: 4MW)	22	22
Fault Recorders Triggered (<0.9 pu)	95	177

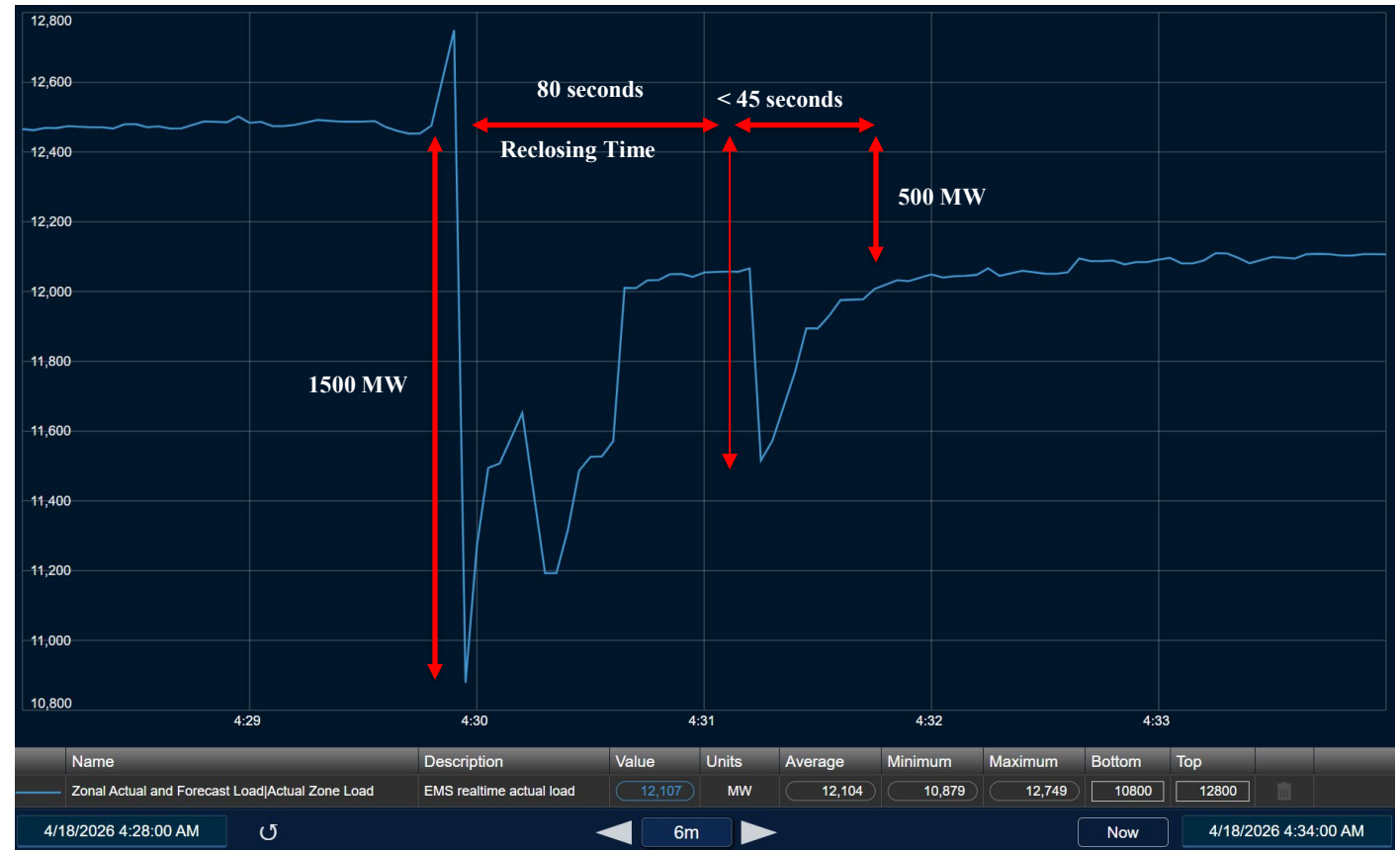


[1] "Considering Simultaneous Voltage-Sensitive Load Reductions," North American Electric Reliability Corporation (NERC) Report, January 2025.

[2] N. S. Ghiasi, O. D. Adeosun, N. A. Rice, R. Chakraborty, F. A. Zelaya-Arrazabal, "Implications of Ride-Through Requirements for Grid-Responsive Data Center Loads: Lessons from Two Transmission Disturbance Events in the Dominion Energy Service Territory", CIGRE USNC Grid of the Future Symposium, Richmond, Virginia, USA, October 2026. (under review)

System Load Review for April 18, 2026

- April 18, 2026, 4:29:42 AM
- 500 MW data center load transfer – reconnected back in less than 90 mins;
- 1000 MW back in less than 2 minutes;
- Total post-fault load response of 1500 MW;
- 53 transformers from about 22 substations experienced Load changes of $> 4\text{MW}$;
- No voltage swell alarm were seen through the system during the event.
No operator action was required.

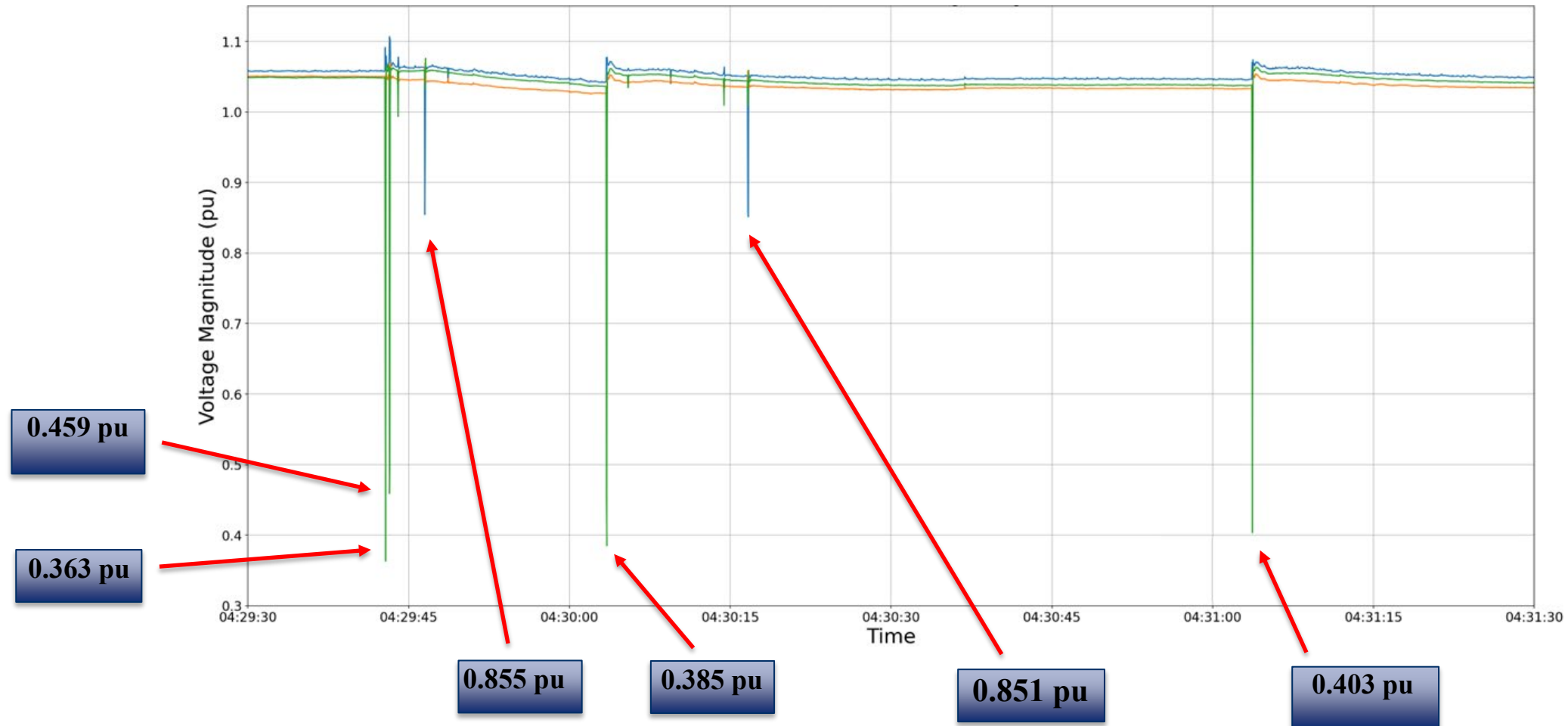


Total System Load (MW)

[2] N. S. Ghiasi, O. D. Adeosun, N. A. Rice, R. Chakraborty, F. A. Zelaya-Arrazabal, "Implications of Ride-Through Requirements for Grid-Responsive Data Center Loads: Lessons from Two Transmission Disturbance Events in the Dominion Energy Service Territory", CIGRE USNC Grid of the Future Symposium, Richmond, Virginia, USA, October 2026. (under review)

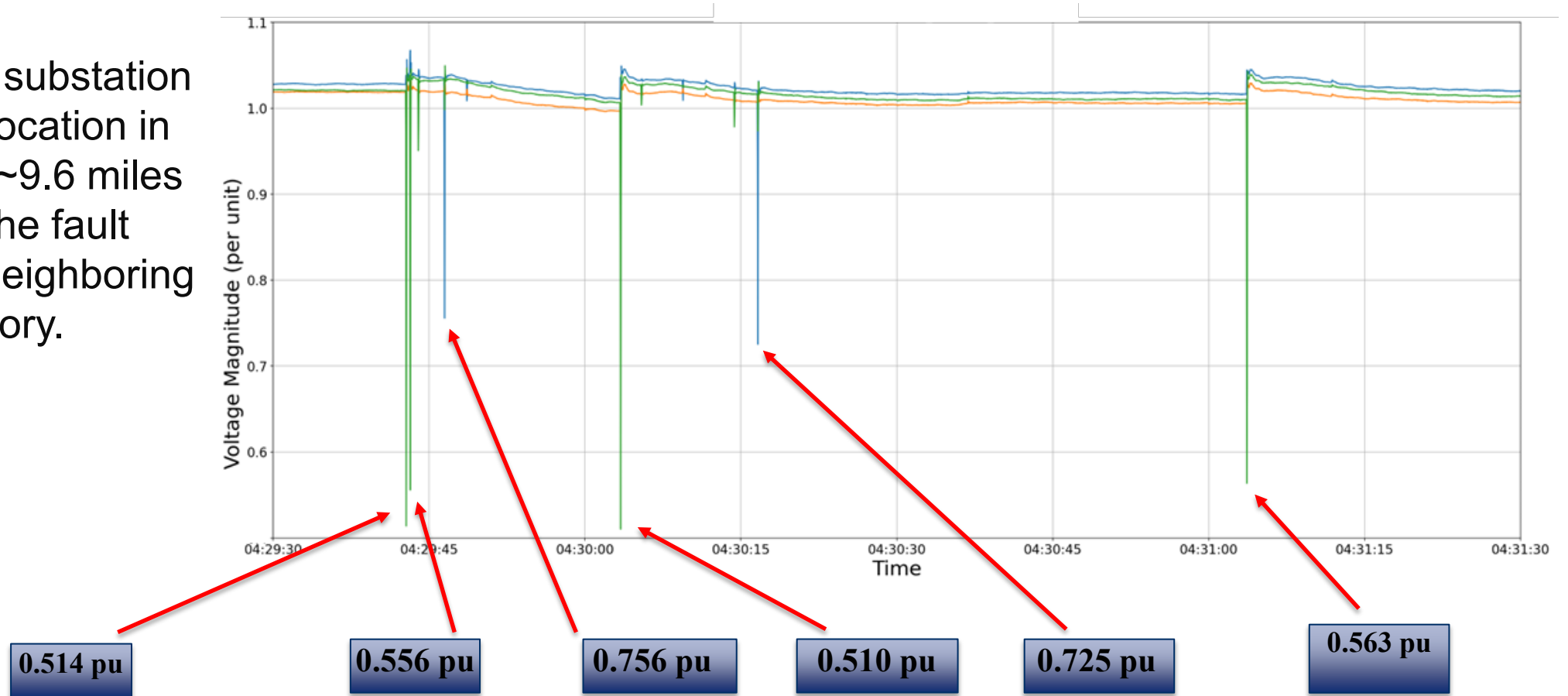


Voltages on the Nearest Substation (500 kV) for April 18, 2026



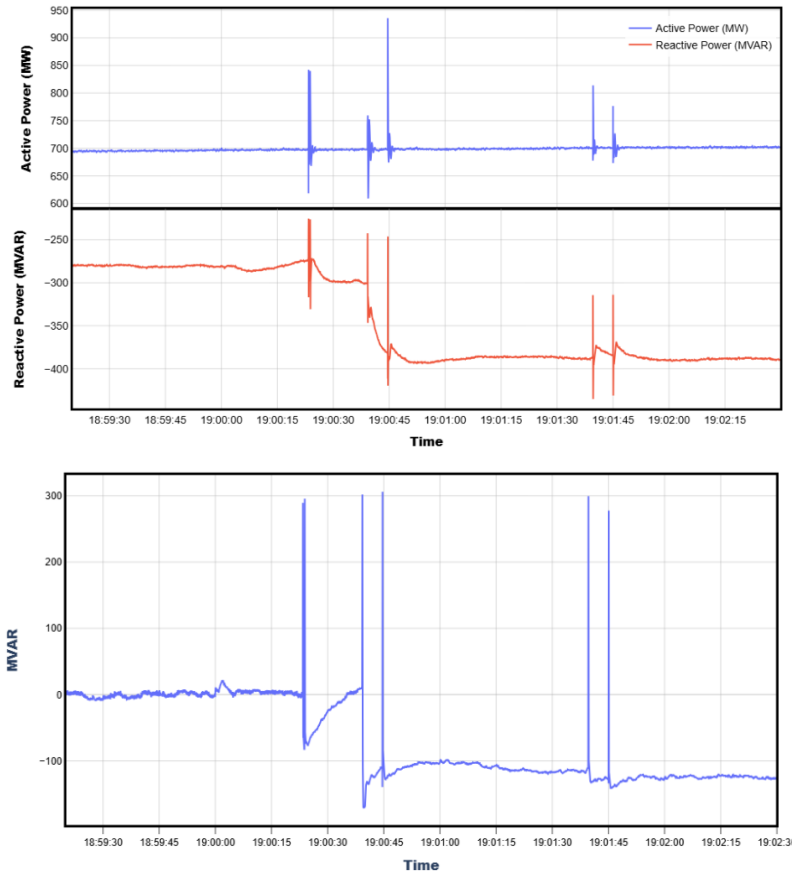
Voltages on the Nearest Substation (230 kV) for April 18, 2026

- The closest substation to the fault location in DOM Zone ~9.6 miles away from the fault location in neighboring utility's territory.



System Response Comparison for disturbance events

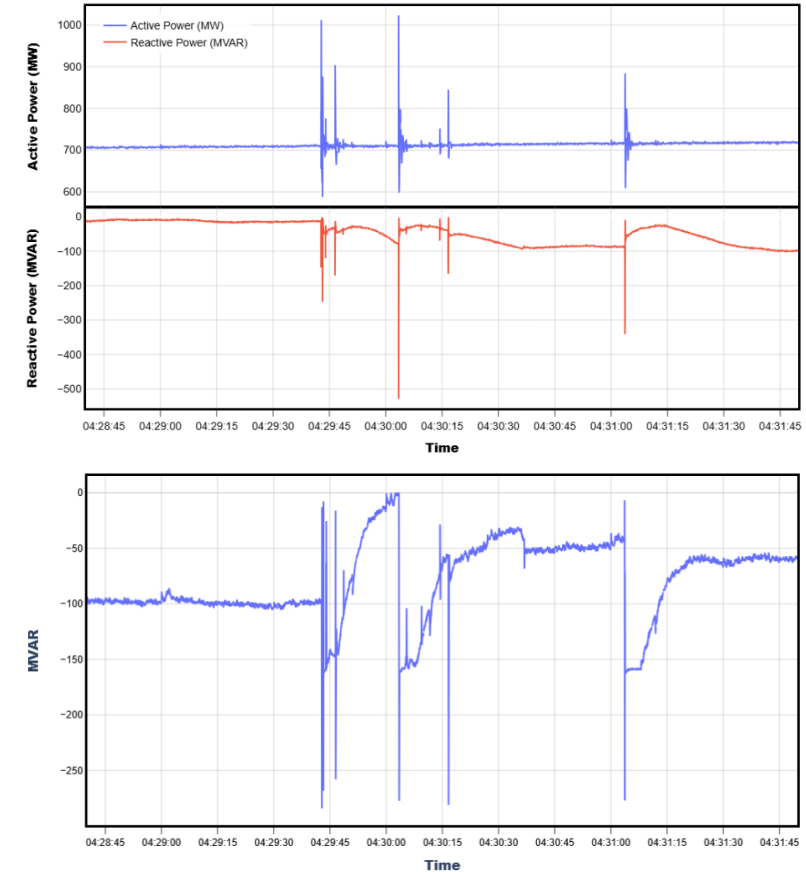
July 10, 2024



Generator
response

FACTs
response

April 18, 2026



[2] N. S. Ghiasi, O. D. Adeosun, N. A. Rice, R. Chakraborty, F. A. Zelaya-Arrazabal, "Implications of Ride-Through Requirements for Grid-Responsive Data Center Loads: Lessons from Two Transmission Disturbance Events in the Dominion Energy Service Territory", CIGRE USNC Grid of the Future Symposium, Richmond, Virginia, USA, October 2026. (under review)



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How did individual data centers react on April 18, 2026?

50 POI metering were analyzed.

Most data centers experienced 6 voltage sags (initial fault and instantaneous reclosing, reclosing at 20 sec and 80 sec, based on Dominion recloser settings).

- 1 datacenter experienced 85 mins of load transfer (Customer 1).
- 3 data centers experienced 100% momentarily load transfer but reconnected back to transmission network in less than 30 mins (Customer 2).
- 9 data centers experience partial load transfer (less than 34%) but reconnected back to transmission network in less than 2 mins.
- Voltage sag durations up to 67 ms with minimum magnitude of 63.27%.

[2] N. S. Ghiasi, O. D. Adeosun, N. A. Rice, R. Chakraborty, F. A. Zelaya-Arrazabal, "Implications of Ride-Through Requirements for Grid-Responsive Data Center Loads: Lessons from Two Transmission Disturbance Events in the Dominion Energy Service Territory", CIGRE USNC Grid of the Future Symposium, Richmond, Virginia, USA, October 2026. (under review)



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Customer 1 – Comparison to July 10 Event

	July 10, 2024					April 18, 2026				
Data Center	V_Sag Alarm	Voltage (pu)	Max V_Sag Duration	Load loss profile	Sustained transfer	V_Sag Alarm	Voltage (pu)	Max V_Sag Duration	Load loss profile	Sustained transfer
DC 1	N	0.91	0.058	No Load Loss	N	4	0.774	0.058	-	N
DC 2	N	0.92	0.049	No Load Loss	N	4	0.758	0.059	Rode through	N
DC 3	N	1	0	No Load Loss	N	4	0.766	0.058	Rode through	N
DC 4	6	0.8377	0.059	Total loss instantaneously and ramp up, Total loss after 3rd shot	Yes	5	0.713	0.059	Rode through	N
DC 5	6	0.6828	0.075	Total Load Loss after 3rd shot	Yes	6	0.652	0.066	Rode through	N
DC 6	4	0.883	0.042	No load loss	N	6	0.651	0.059	Rode through	N
DC 7	6	0.7446	0.067	Total Load Loss after 3rd shot	Yes	6	0.652	0.058	100% load transfer for 85 mins and then ramp up in 14 mins	Yes
DC 8	6	0.7477	0.067	Total Load Loss after 3rd shot	Yes	5	0.717	0.059	Rode through	N
DC 9	N	0.88	0.057	No Load Loss	N	6	0.711	0.058	Rode through	N
DC 10	6	0.7924	0.058	Minimal drop initially, all off at 15 sec	Yes	6	0.716	0.059	Rode through	N
DC 11	6	0.7905	0.066	Total Load Loss after 3rd shot	Yes	6	0.701	0.058	Rode through	N
DC 12	6	0.8192	0.066	Minimal drop initially, all off at 15 sec	Yes	6	0.636	0.067	Rode through	N
DC 13	6	0.7792	0.058	Total Load Loss after 3rd shot	Yes	6	0.72	0.059	Rode through	N
DC 14	6	0.784	0.067	Total Load Loss after 3rd shot	Yes	5	0.721	0.059	Rode through	N
DC 15	6	0.7847	0.067	Total Load Loss after 3rd shot	Yes	6	0.633	0.067	Rode through	N

[2] N. S. Ghiasi, O. D. Adeosun, N. A. Rice, R. Chakraborty, F. A. Zelaya-Arrazabal, "Implications of Ride-Through Requirements for Grid-Responsive Data Center Loads: Lessons from Two Transmission Disturbance Events in the Dominion Energy Service Territory", CIGRE USNC Grid of the Future Symposium, Richmond, Virginia, USA, October 2026. (under review)



Customer 2 – Comparison to July 10 Event

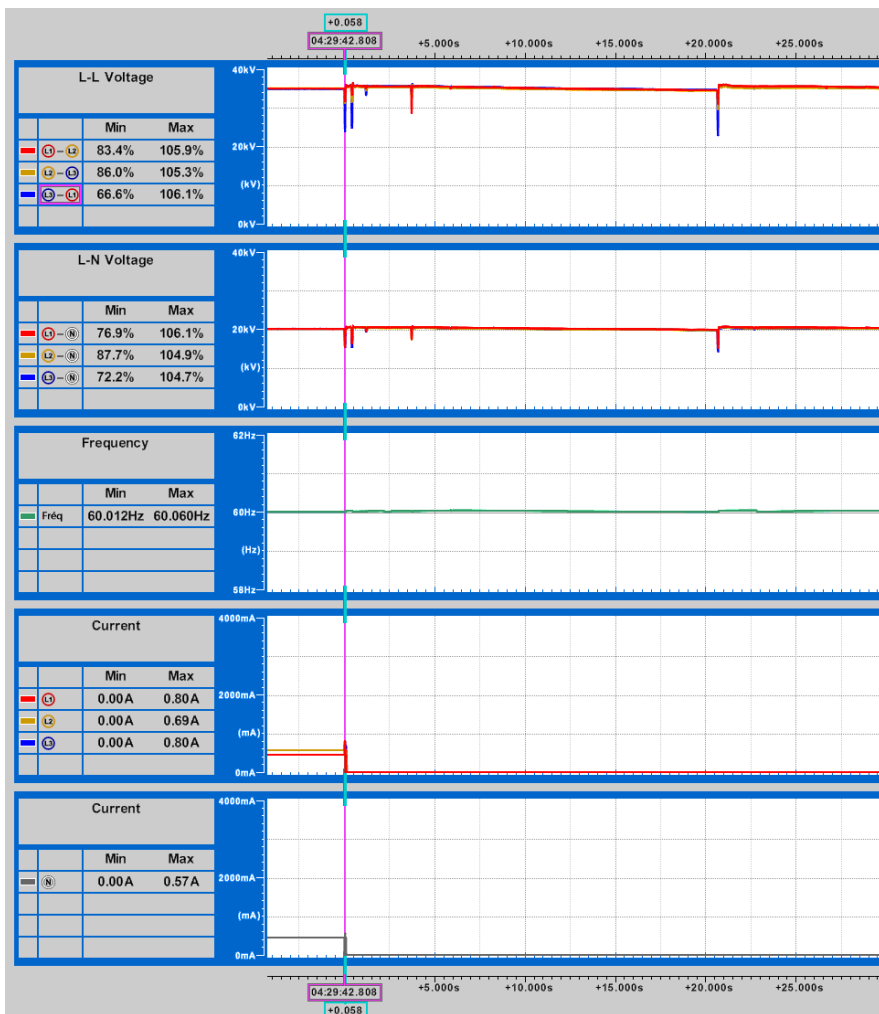
- 3 data centers experienced 100% momentarily load transfer but reconnected back to network in less than 30 mins.
- This table compares their responses during April 18 event with July 10, 2024 event.

	July 10					April 18				
Data Center	V_Sag Alarm	Voltage (pu)	Max V_Sag Duration	Load loss profile	Sustained Transfer	V_Sag Alarm	Voltage (pu)	Max V_Sag Duration	Load loss profile	Sustained Transfer
DC 16	6	0.7544	0.067	Minimal Current	N	6	0.666	0.067	100% load transfer and then ramp up in 28 mins	N
DC 17	N	0.862	0.058	No load loss	N	5	0.734	0.059	Rode through	N
DC 18	6	0.8654	0.05	No load loss	N	4	0.768	0.058	Rode through	N
DC 19	6	0.6898	0.075	No load loss	N	6	0.656	0.067	100% load transfer for 2 mins and then ramp up in 20 mins	N
DC 20	6	0.6943	0.075	Had no load at time of fault	N	6	0.653	0.067	Rode through	N
DC 21	6	0.7601	0.067	No load loss	N	6	0.679	0.067	100% momentarily load transfer and then ramp up in 15 mins	N

[2] N. S. Ghiasi, O. D. Adeosun, N. A. Rice, R. Chakraborty, F. A. Zelaya-Arrazabal, "Implications of Ride-Through Requirements for Grid-Responsive Data Center Loads: Lessons from Two Transmission Disturbance Events in the Dominion Energy Service Territory", CIGRE USNC Grid of the Future Symposium, Richmond, Virginia, USA, October 2026. (under review)



Customer 2 – DC #16



Sag#	Time	Mag (%)	Duration (ms)
1	4:29:42.808	69.6	58

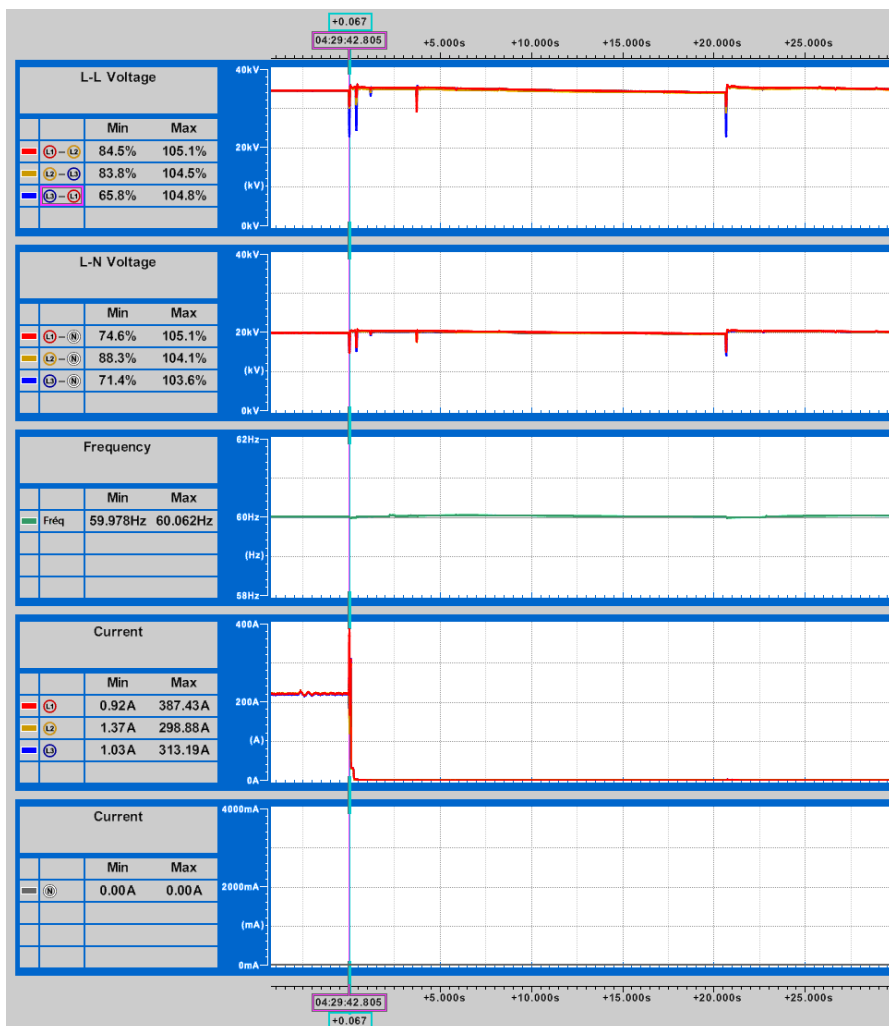
Ramp_rate = 1.04 MW/min



- 100% of the data center load transferred for 1 minute and then ramped up in 28 mins with a rate of 1.04 MW/min.
- The transfer happened on the first voltage sag.

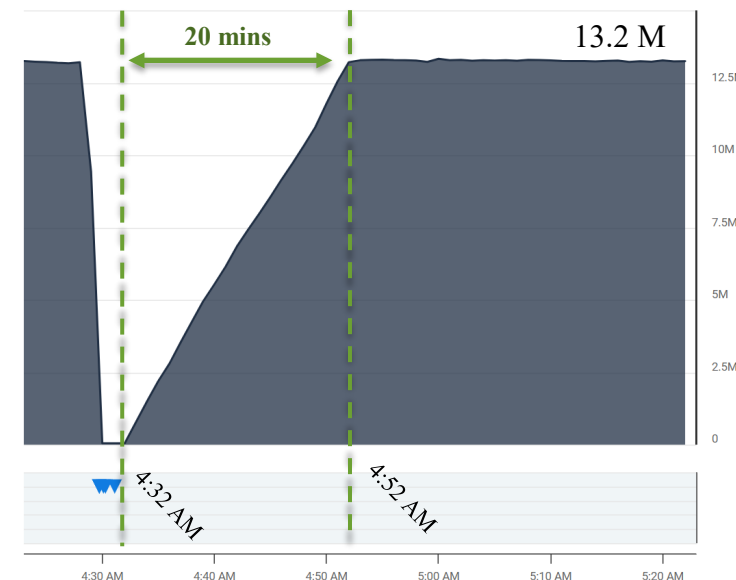


Customer 2 – DC #17



Sag#	Time	Mag (%)	Duration (ms)
1	4:29:42.805	65.8	67

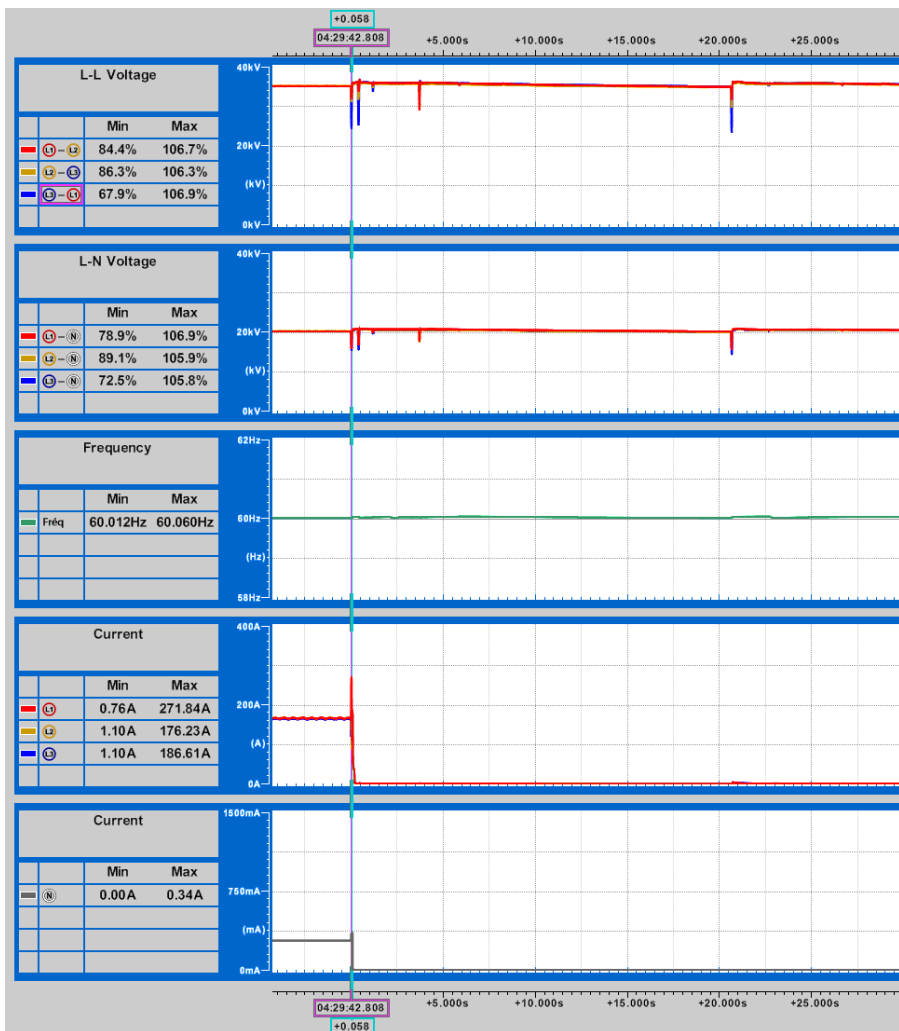
Ramp_rate = 0.7 MW/min



- 100% of the data center load transferred for 2 minutes and then ramped up in 20 mins with a rate of 0.7 MW/min.
- The transfer happened on the first voltage sag.

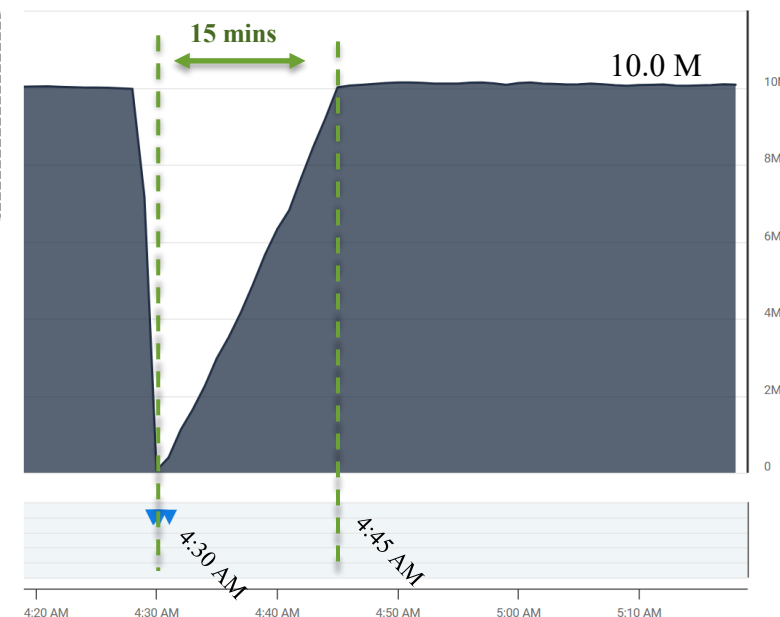


Customer 2 – DC #18



Sag#	Time	Mag (%)	Duration (ms)
1	4:29:42.808	71.2	58

Ramp_rate = 0.7 MW/min



- 100% of the data center load transferred and immediately ramped up in 15 mins with a rate of 0.7 MW/min.
- The transfer happened on the first voltage sag.



General Observation

- About 1500 MW of load instantaneously responded, but 1000 MW recovered within less than 45 seconds after the reclosing shots.
- The remaining 500 MW ramped in less than 90 minutes.
- No substation experienced overvoltage.
- No DE system operation action was required.
- Most datacenters saw 6 voltage sags, corresponding to the initial fault and reclosing operations.
- Fault location is ~9.6 miles from Dominion Energy's substation, in neighboring utility's territory.

[2] N. S. Ghiasi, O. D. Adeosun, N. A. Rice, R. Chakraborty, F. A. Zelaya-Arrazabal, "Implications of Ride-Through Requirements for Grid-Responsive Data Center Loads: Lessons from Two Transmission Disturbance Events in the Dominion Energy Service Territory", CIGRE USNC Grid of the Future Symposium, Richmond, Virginia, USA, October 2026. (under review)



Key Takeaways

- EMT modeling is essential in representing the high complexity of large load facilities, controls, and performance.
- Regulator - ISO - Utility close collaboration needed to tackle wider scope of analysis:
 - Decide **the triggering criteria for EMT** analysis for studying delivery point applications during reliability planning phase.
 - Case building for credible scenario analysis of TO system – load pocket **proximity to series compensated lines, vicinity to HVDC converter stations**.
 - Develop EMT study workflows that can handle multi-GW load clusters.
- Relative to previous comparable disturbance events, less load were transferred on April 18, although a broader geographical area was impacted.
- This outcome indicates the effectiveness of coordinated efforts with customers to improve ride-through settings.
- Additional customers have been identified for targeted engagement to further enhance system performance under similar conditions.



Strategic Initiatives and Special Studies Team for Data Center

Leadership Team



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