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Utility Perspective of Large Loads

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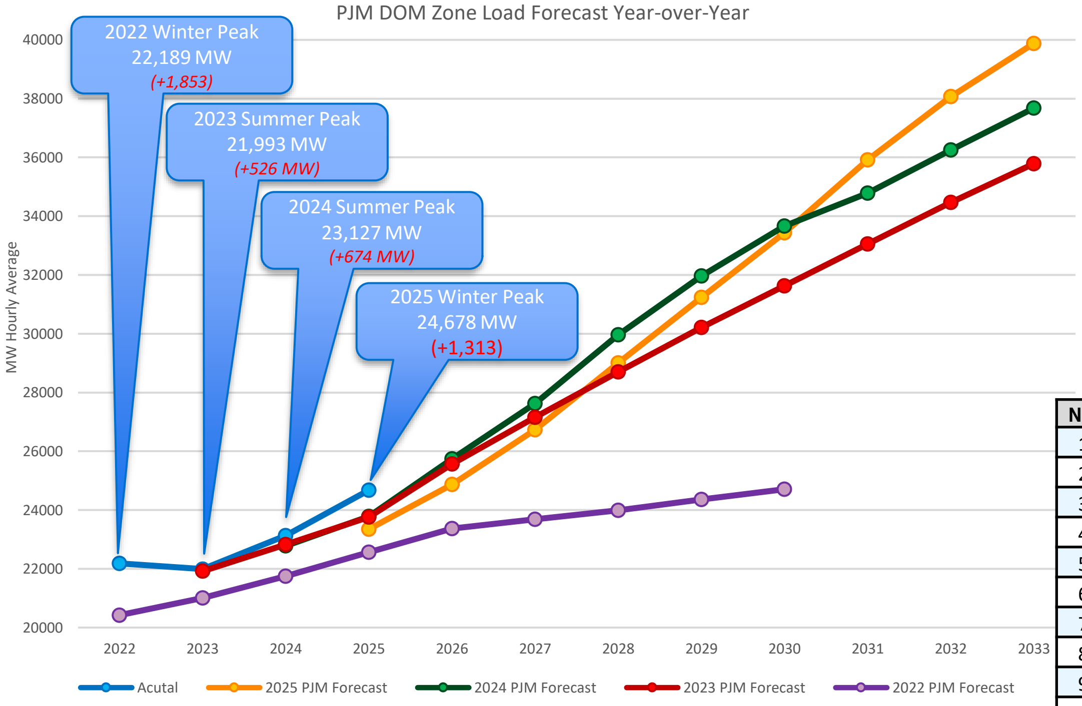
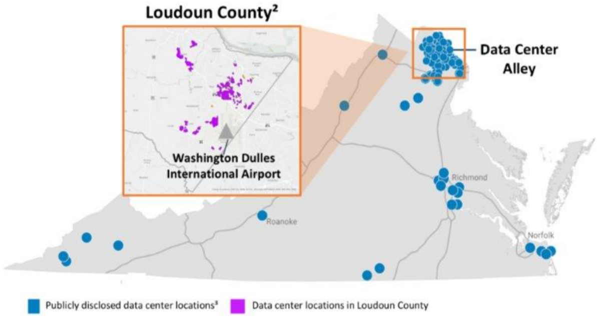
Year-over-year PJM DOM Zone forecast

Zonal 10/15 Year Load Growth		
SUMMER	5.6%	4.8%
WINTER	5.1%	4.3%





²February 2022 Loudoun County Data Center Land Study
³Data Center locations provided by Data Center Hawk

No.	Date	Temp	Peak
1	1/23/2025	9	24,678
2	1/22/2025	12	23,573
3	1/21/2025	12	23,355
4	7/16/2024	98	23,127
5	7/17/2024	97	22,675
6	7/15/2024	97	22,622
7	7/9/2024	96	22,545
8	7/5/2024	99	22,522
9	1/16/2025	13	22,474
10	1/24/2025	17	22,405

Top 10 Peak Days all within last year

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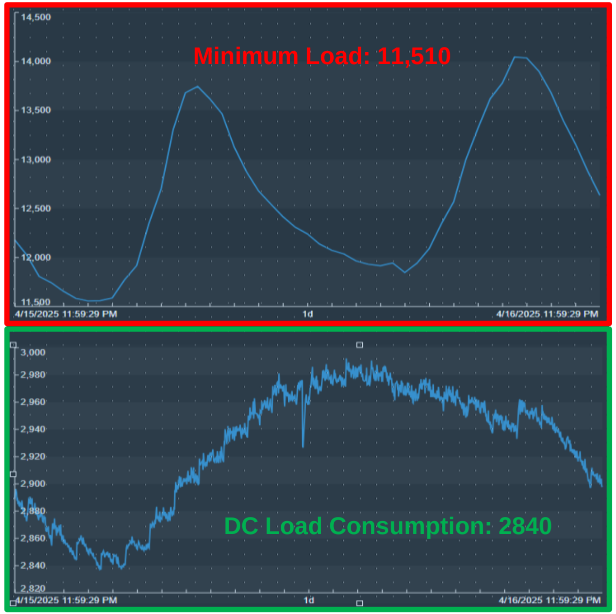
Load Patterns: System Load vs. Data Center Load

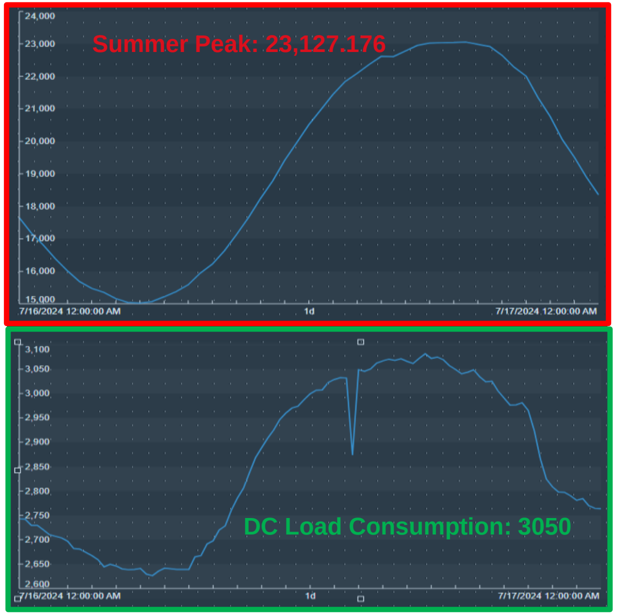
Observations:

- Data Center Load Variation: Proportion of DC load varies significantly by season, ranging from 13.2% to 25% of total load.
- Spring vs. Summer Load: Total DVP load drops to 40% in spring compared to summer, while DC load remains high at 85% of its summer peak.
- Summer Load Trends: DC load profile in summer mirrors the overall load profile in the DVP area but differs in spring.

2025 Spring Light Load day (MW)



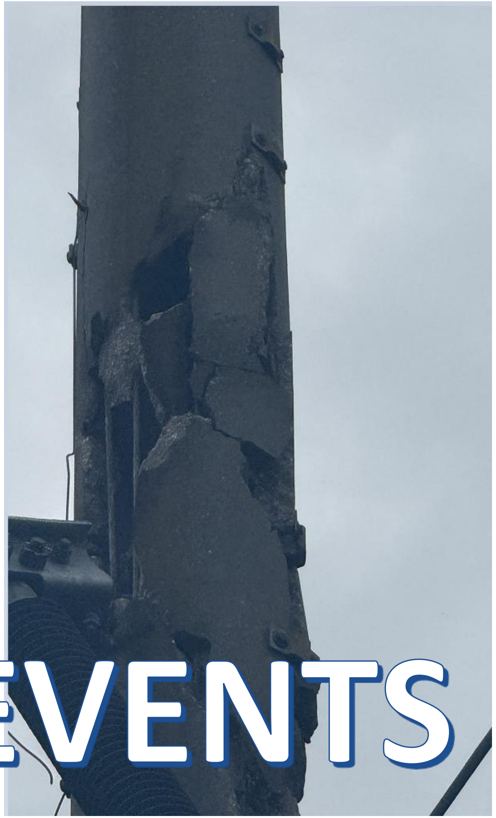
2024 Summer Peak Load day (MW)



Take away:

Data center load modeling needs special consideration in operations planning time horizon

LOAD TRANSFER EVENTS



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Load Transfer Events

Five load transfer events from 500 – 1700 MWs since July 2024

- All events were line lockouts in general Northern VA area
    - Inside *and outside* of Loudoun County data center alley area
    - All transmission protection functioned exactly as designed

- Load returned after 3+ hours for the first & second events

- Impacted between 18 – 31 substations depending on event

- Data center recovery profile differed across customers
    - Some differences in the same customer based on design of facility

- Required many meetings across customers to understand variation in responses

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Event 1

July 10, 2024

Overview of Event 1

Date: Wednesday, July 10, 2024, 19:00 EST

Event: 230 kV line lockout during a storm after completing reclosing cycles due to a failed lightning arrester with **no direct** customer load impacted

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Post Event Analysis – Event 1

- 1,551 MWs of data center load transferred to long-term backup generation during normal transmission protection reclosing
  - 25,000-amp fault cleared correctly in 2.75 cycles (45.8 milliseconds)
  - Line length is 0.30 miles
  - Line protection is SEL-411L’s in differential mode
- **22 substations impacted**
  - 4 MW to 235 MW with an average of 70.5 MW
- *Impacted area was approximately 4.0 sq. miles, but as far away as 32 transmission-line miles away*

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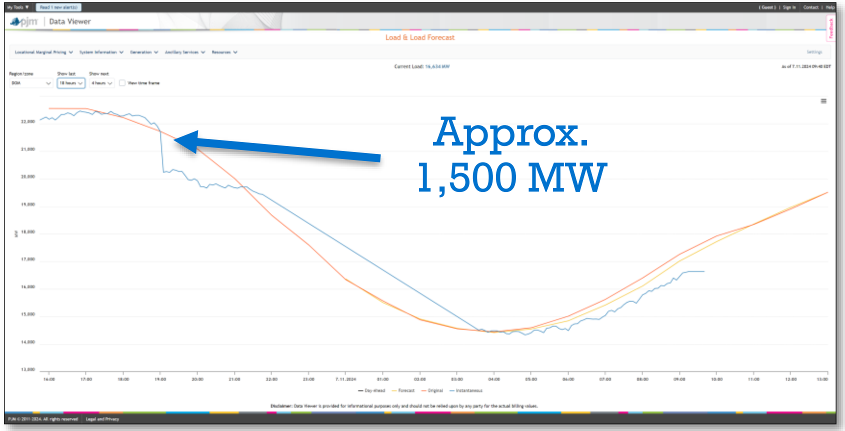
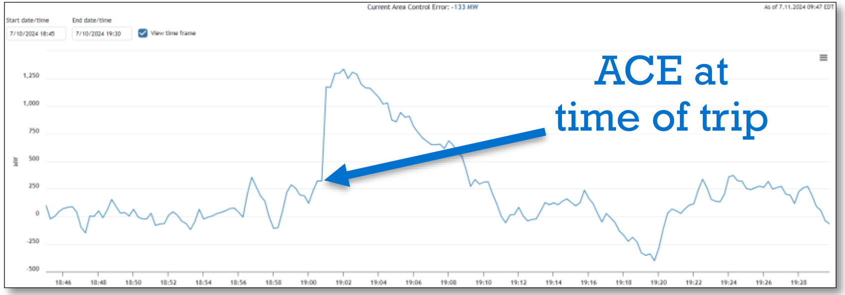
Operational Impacts – Event 1

- PJM and Dominion Energy's System Operators determined approximately 1,500 MW of load had been removed from the system
- ET System Operators determined numerous data centers had transferred to their backup generation unexpectedly





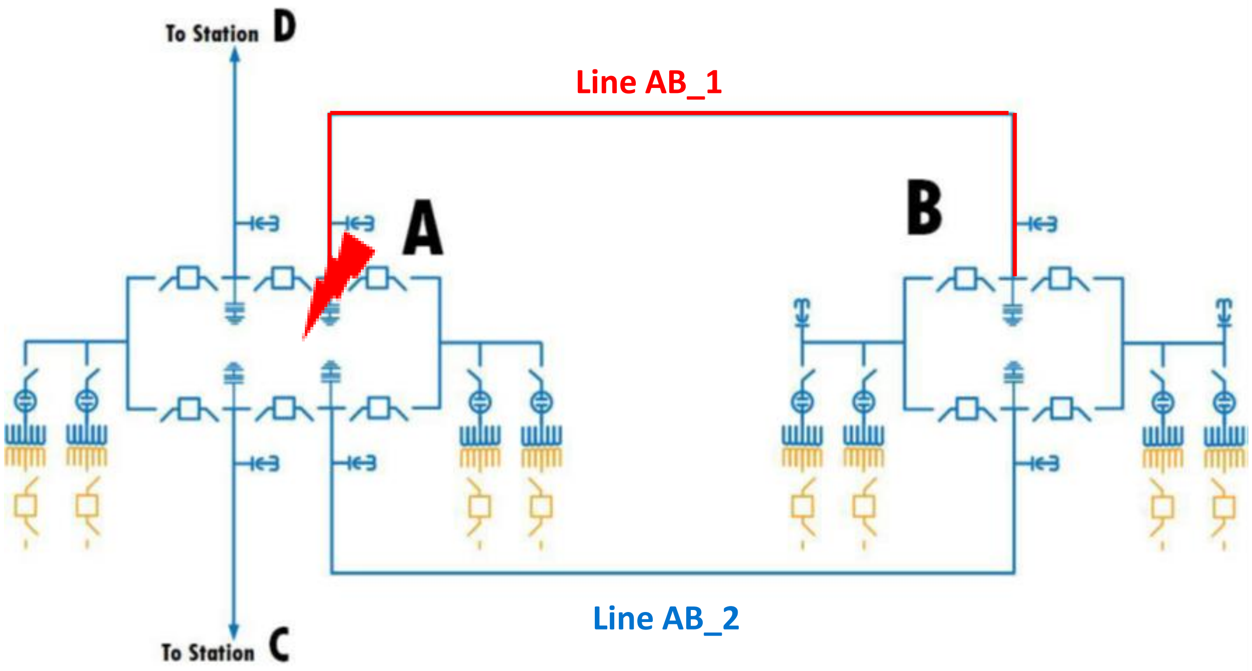
View of Fault Location : Substation A and Substation B

Fault Location:

Substation A

Fault Isolation:

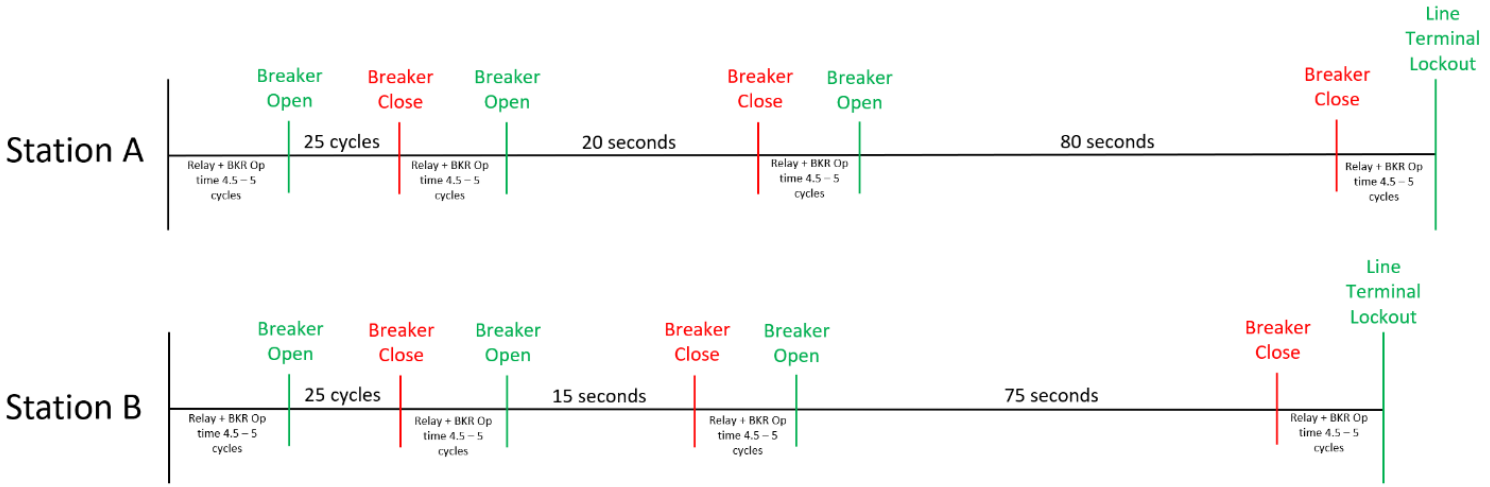
5 reclosing shots and lockout of Line AB_1



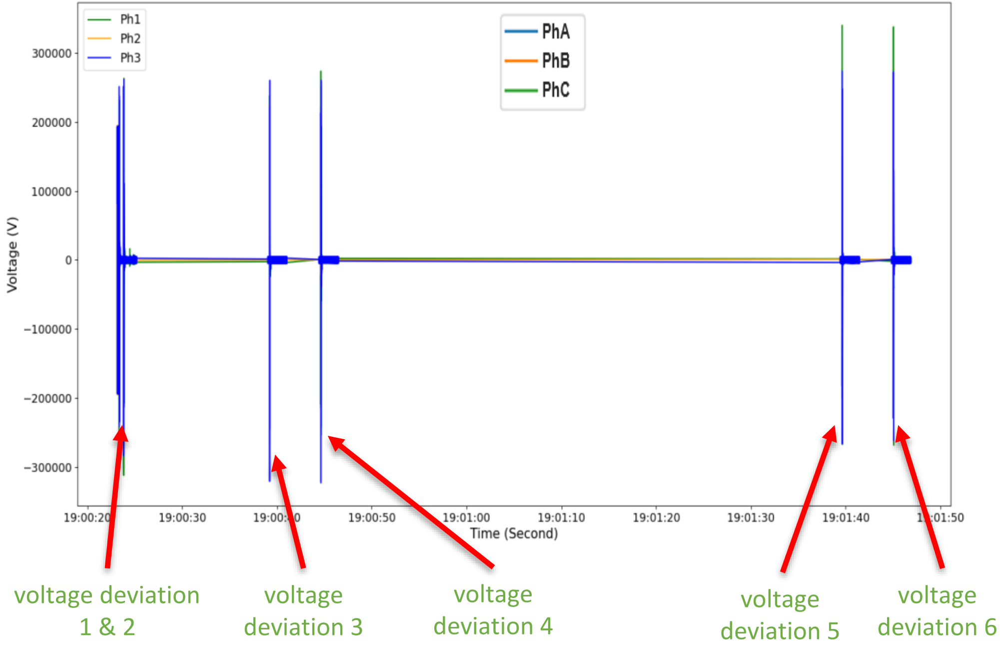
Transmission Protection Overview of Event

Reclosing Attempts

Fault Cleared	Reclose Attempt	Substation A Reclose	Substation B Reclose
2.75 cycles (45.8 ms)	1st	Instantaneous	Instantaneous
4.5 cycles (75 ms)	2nd	20 seconds	15 seconds
4.5 cycles (75 ms)	3rd	80 seconds	75 seconds



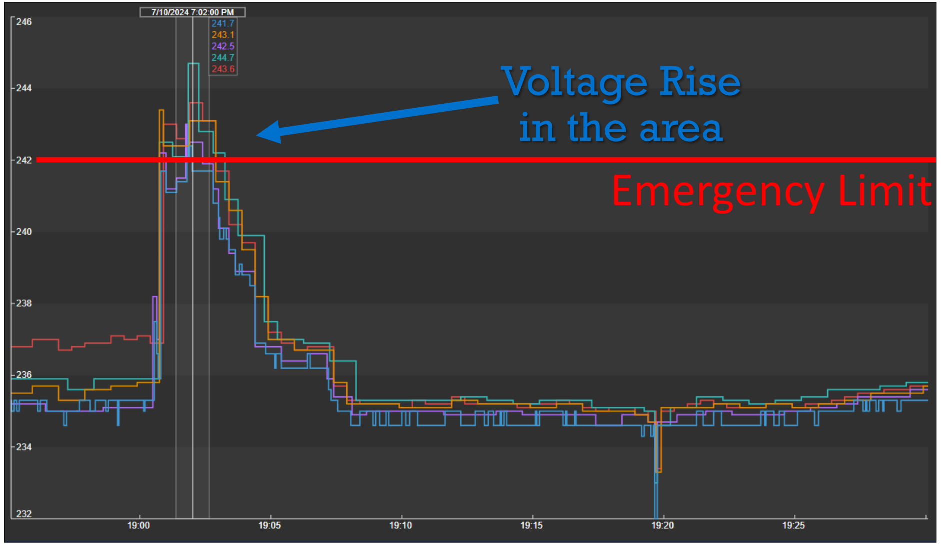
Voltage Profile: Faulted Line AB_1



Voltage Deviation	Associated Cause
Voltage Deviation 1	Initial fault
Voltage Deviation 2	Instantaneous reclosing of breakers at substations A and B
Voltage Deviation 3	First timed reclosing of breaker at substations A
Voltage Deviation 4	First timed reclosing of breaker at substations B
Voltage Deviation 5	Second timed reclosing of breaker at substations A
Voltage Deviation 6	Second timed reclosing of breaker at substations B

Operational Impacts – Event 1

- System Operators experienced high voltage rise (approx. 10 kV)
    - System Operators took immediate action by removing nine 230 kV capacitor banks in the area within seven minutes to return to nominal voltage



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How did individual data centers react?

- ET network is fully observable with synchrophasor and/or digital fault recorder point-on-wave metering
  - Transmission substation-level metering
  - Insufficient to determine data center dynamic response

- Point-of-interconnection (POI) metering
  - PQ meters installed at data center POI
  - Limited installation: 51 data centers

Some data center companies response differed across facilities

If one customer is fed by one feeder, that measurement may be sufficient. Effective Root Cause Analysis requires the ability to isolate individual data centers to remove any ambiguity between multiple data centers served from the same feed.

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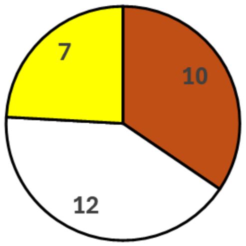
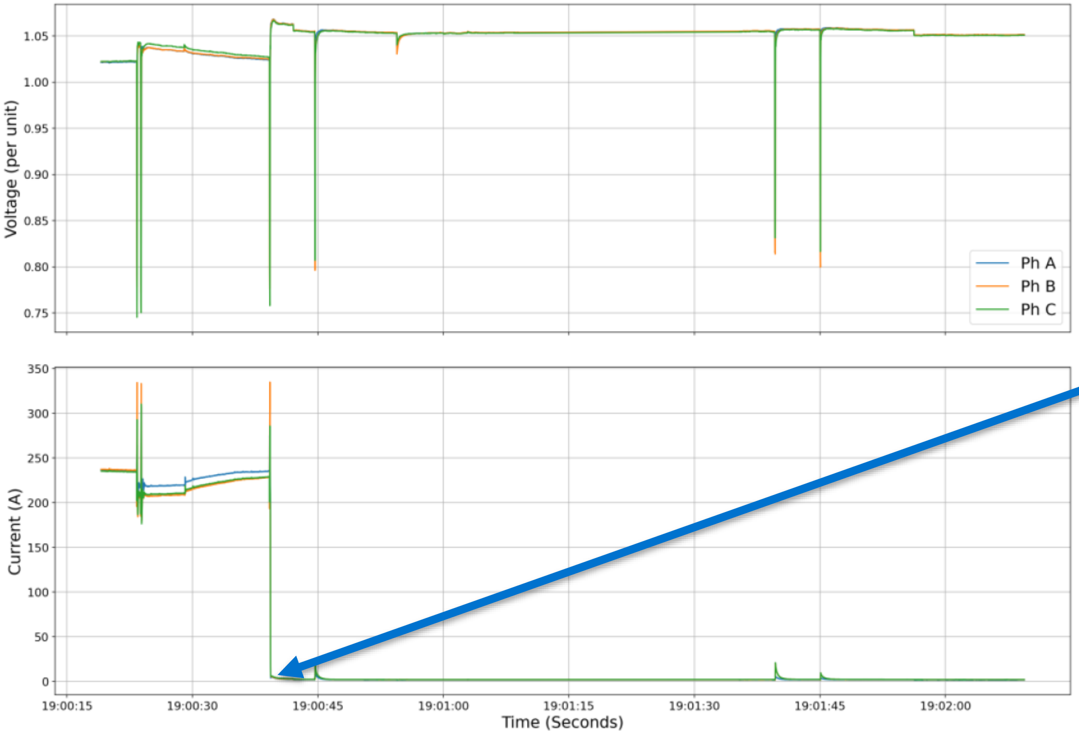
POI Metering Review

- 29 data centers with POI metering in the affected substations were reviewed.



Data Center	Distance from Fault (mi)	Load Profile	Load Transfer	Sustained Transfer
DC_22	0	Initial drop in load profile but load recovered	Y	No
DC_23	0	Initial drop in load profile but load recovered	Y	No
DC_24	0	Initial drop in load profile but load recovered	Y	No
DC_11	3.28	Rode through	N	No
DC_6	3.54	Rode through	N	No
DC_7	3.54	Rode through	N	No
DC_9	3.54	Rode through	N	No
DC_8	3.54	Initial drop in load profile but load recovered	Y	No
DC_4	3.54	Initial drop in load profile, and sustained loss after third reclosin	Y	Yes
DC_5	3.54	Initial drop in load profile, and sustained loss after third reclosin	Y	Yes
DC_19	3.75	Rode through	N	No
DC_18	3.75	Initial drop in load profile, and sustained loss after third reclosin	Y	Yes
DC_29	4.06	Initial drop in load profile but load recovered	Y	No
DC_16	4.12	Rode through	N	No
DC_15	4.12	Initial drop in load profile but load recovered	Y	No
DC_12	4.12	Initial drop in load profile, and sustained loss after third reclosin	Y	Yes
DC_13	4.12	Initial drop in load profile, and sustained loss after third reclosin	Y	Yes
DC_14	4.12	Initial drop in load profile, and sustained loss after third reclosin	Y	Yes
DC_25	4.68	Rode through	N	No
DC_1	5.16	Rode through	N	No
DC_3	5.16	Rode through	N	No
DC_2	5.16	Initial drop in load profile but load recovered	Y	No
DC_20	5.45	Rode through	N	No
DC_21	5.45	Rode through	N	No
DC_10	7.41	Initial drop in load profile, and sustained loss after third reclosin	Y	Yes
DC_26	13.93	Initial drop in load profile, and sustained loss after third reclosin	Y	Yes
DC_27	13.93	Initial drop in load profile, and sustained loss after third reclosin	Y	Yes
DC_28	13.93	Initial drop in load profile, and sustained loss after third reclosin	Y	Yes
DC_17	32	Rode through	N	No

Operational Impacts – Data Center 1



Example of
Data Center "1"
which transferred to
back up generation.

 November 3, 2025

Source: Dominion Energy high fidelity monitoring at data center point of interconnection

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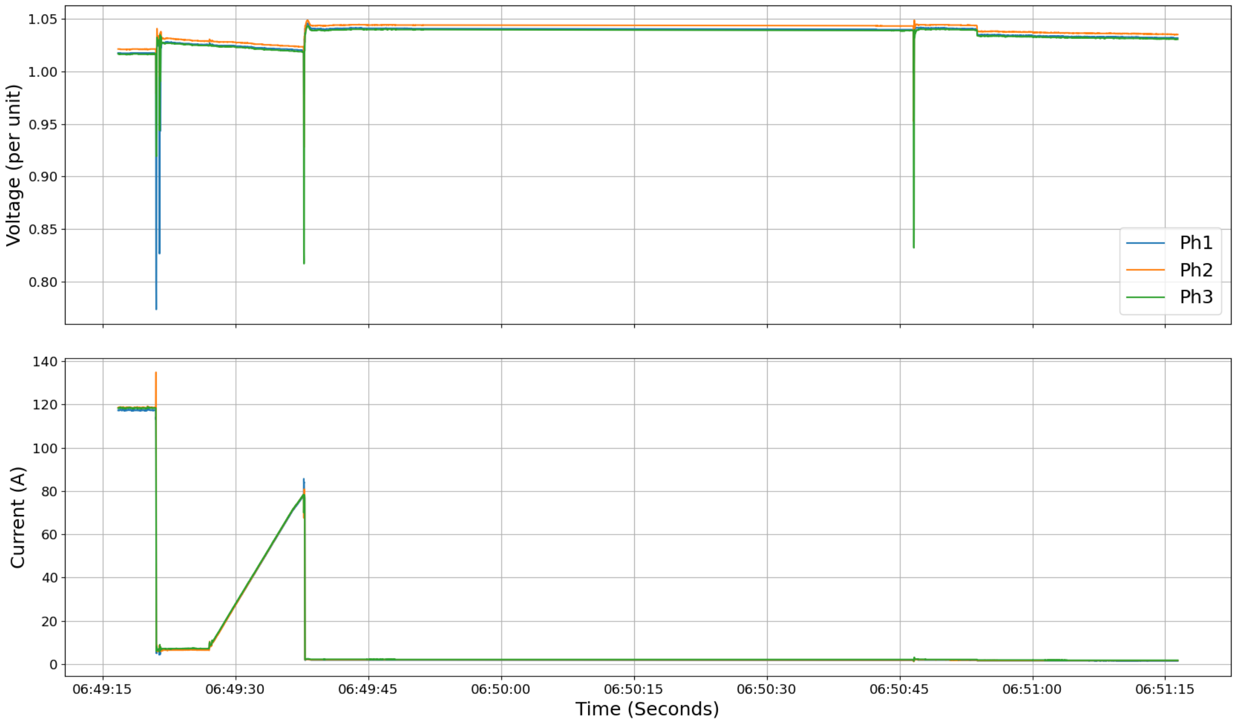
Operational Impacts – Data Center 2

Example of
Data Center "2"
which recovered from
fault after temporarily
reducing load

 November 3, 2025

Source: Dominion Energy high fidelity monitoring at data center point of interconnection

Operational Impacts – Data Center 3



Example of
Data Center "3"
which recovered after initial
fault but sustained transfer
after third voltage deviation

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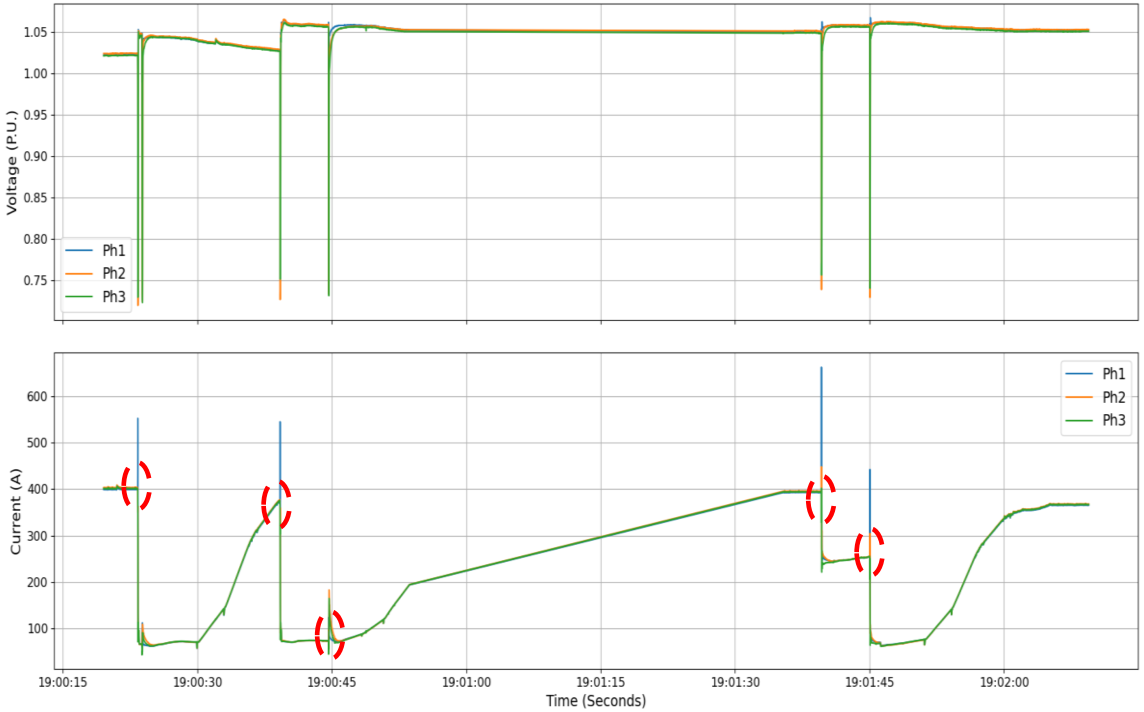
Operational Impacts – Data Center 4



Example of Data Center "4" which saw load drops at each reclosing shot, but starts to recover

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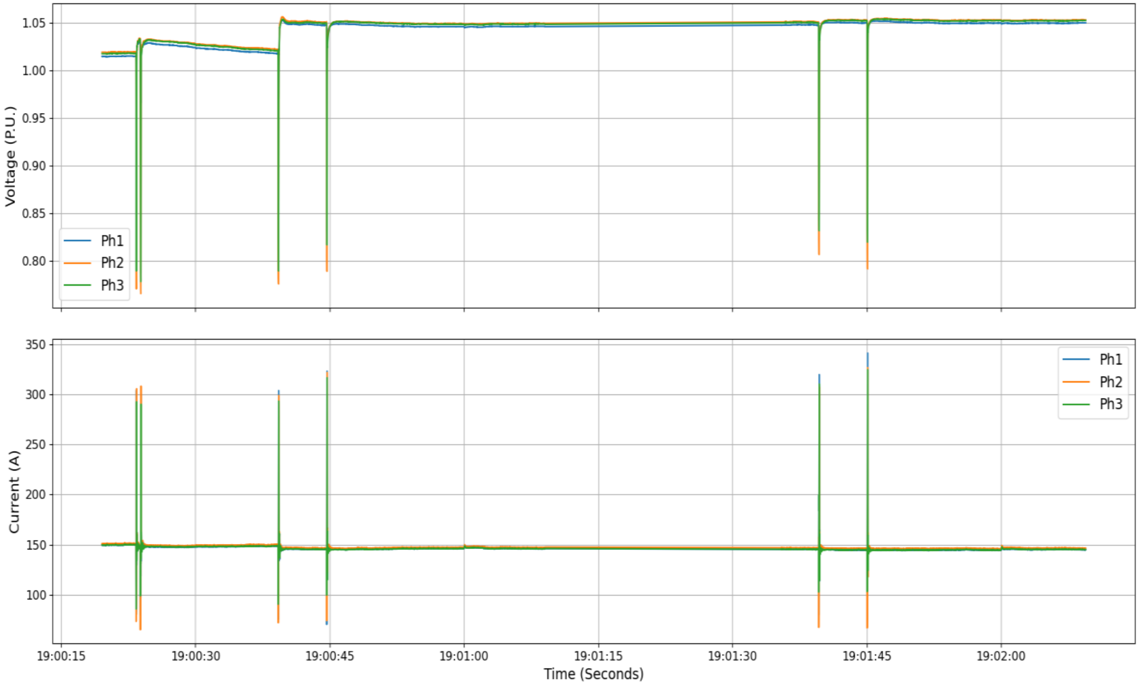
Operational Impacts – Data Center 5



Example of Data Center "5" which saw no load loss and road through the events

Event 2

February 17, 2025

Overview of Event 2

- February 17th, 2025 at 06:49 EST a 230 kV line locked out after completing reclosing cycles due to the tree strike.

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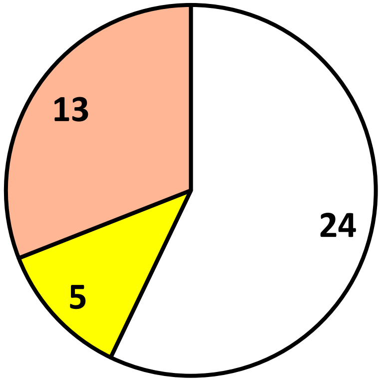
Immediate Post Event Analysis – Event 2

- Data Center load transferred during normal transmission protection reclosing
  - 5,000-amp A-phase to C-phase fault at 2.84 miles from substation A, cleared correctly
  - Inception fault cleared in 5.9 cycles (98.53 milliseconds)
  - Line length is 6.42 miles
  - Line protection is electromechanical impedance relaying
- 1800 MW Data-Center load transferred
  - 544 MW of Co-Op load transferred
- **18 substations impacted**
  - 44 transformers impacted
  - 4 MW to 154 MW with average of 75 MW

POI Metering Review

- 42 data centers with POI metering with Voltage Sag Alarm were reviewed



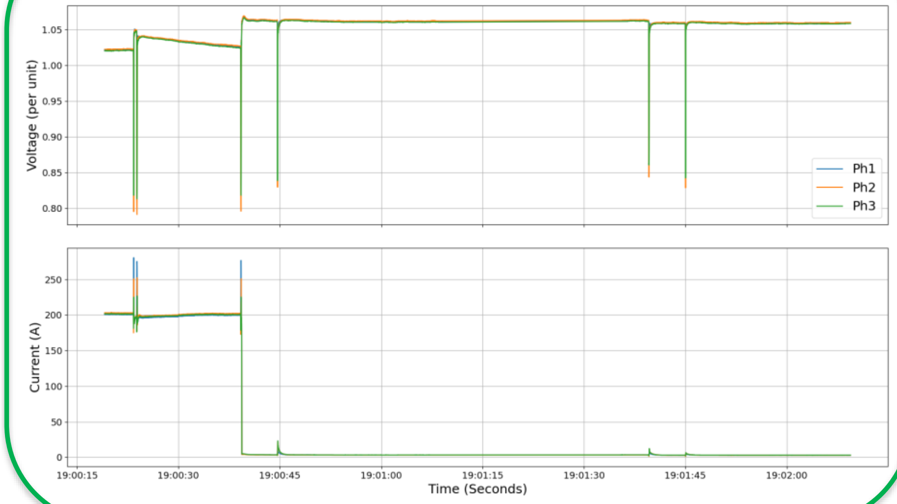
- Rode through
- Initial drop in load profile but load recovered
- Initial drop in load profile, and sustained transfer after third voltage deviation

Data Center	Distance from Fault (mi)	Load Profile	Load Transfer	Sustained Transfer
DC_33	0	about 60% load loss for 8 sec after every shot	Yes	No
DC_34	3.78	about 80% load loss for 6 sec after every shot	Yes	No
DC_50	5.75	Load drop after each shot but dynamicaly recovered within 6 sec	Yes	No
DC_10	15.71	40% Load Loss after 3rd shot	Yes	Yes
DC_48	16.38	20% Load Loss after 3rd shot	Yes	Yes
DC_49	16.38	Rode through	No	No
DC_25	18.44	Rode through	No	No
DC_4	19.58	Total Load Loss after 3rd shot	Yes	Yes
DC_5	19.58	Total Load Loss after 3rd shot	Yes	Yes
DC_6	19.58	Rode through	No	No
DC_7	19.58	Rode through	No	No
DC_8	19.58	Rode through	No	No
DC_9	19.58	Rode through	No	No
DC_20	19.61	~2MVA swing during fault (1.5sec)	Yes	No
DC_1	19.61	Rode through	No	No
DC_2	19.61	Rode through	No	No
DC_21	19.61	Rode through	No	No
DC_3	19.61	Rode through	No	No
DC_36	19.61	Rode through	No	No
DC_11	22.43	~1.2MVA swing during fault (1.5sec)	Yes	No
DC_41	22.43	Rode through	No	No
DC_18	22.9	Total Load Loss after 3rd shot	Yes	Yes
DC_19	22.9	Rode through	No	No
DC_12	23	Total Load Loss after 3rd shot	Yes	Yes
DC_13	23	Total Load Loss after 3rd shot	Yes	Yes
DC_14	23	Total Load Loss after 3rd shot	Yes	Yes
DC_15	23	Rode through	No	No
DC_16	23	Rode through	No	No
DC_22	23.12	Rode through	No	No
DC_23	23.12	Rode through	No	No
DC_24	23.12	Rode through	No	No
DC_29	23.21	Rode through	No	No
DC_31	31.86	Rode through	No	No
DC_26	35.1	Total loss instnateneously and ramp up, Total loss after 3rd shot	Yes	Yes
DC_27	35.1	Total Load Loss after 3rd shot	Yes	Yes
DC_28	35.1	Total Load Loss after 3rd shot	Yes	Yes
DC_17	39.54	Total Load Loss after 3rd shot	Yes	Yes
DC_43	39.78	Total Load Loss after 3rd shot	Yes	Yes
DC_37	>50	Rode through	No	No
DC_38	>50	Rode through	No	No
DC_39	>50	Rode through	No	No
DC_42	>50	Rode through	No	No

Data Center 1

Total load transfer in **Jul 10** but partial load transfer in **Feb 17**

	Min Phase Voltage (per unit)	Max Voltage Sag Duration (ms)
10-Jul	0.7905	79
17-Feb	0.6308	92



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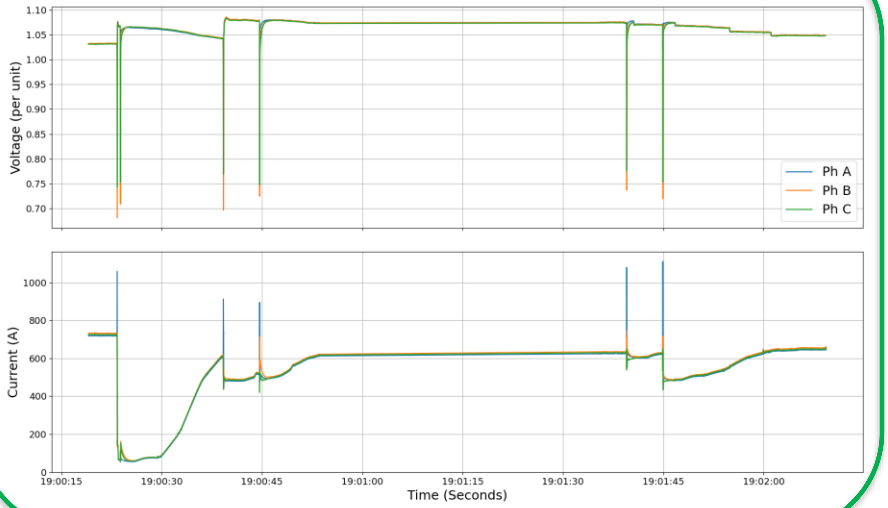
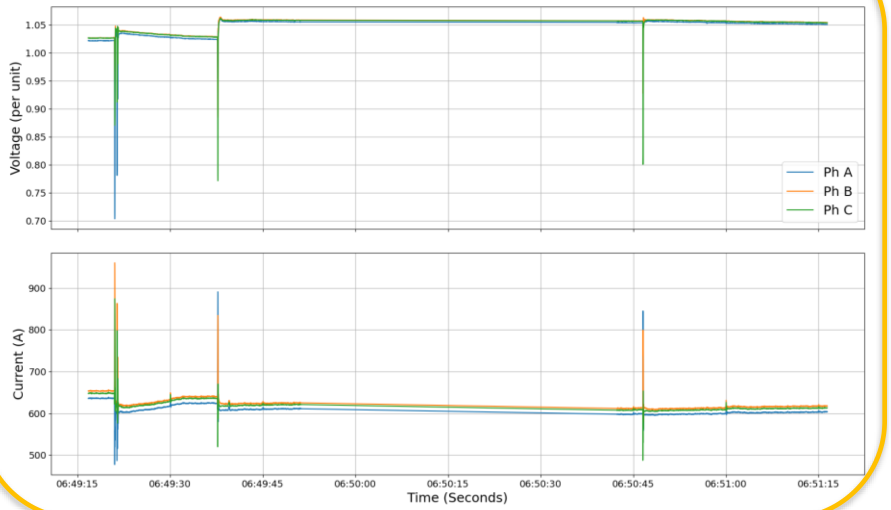
Data Center 2

	Min Phase Voltage (per unit)	Max Voltage Sag Duration (ms)
10-Jul	0. 6805	66
17-Feb	0.7033	91

July 10: Total load transfer during the initial fault but Load Recovered



Feb 17: Load rode through the event



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Event 3

June 19, 2025

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June 19, 2025

- Same line as February 17, 2025 event
  - **Evolving Fault:**
    - 3-Phase (initial fault)
    - Phase-Phase (Instant reclose)
    - Phase to Ground (delayed reclose)

- Most data centers experienced only **2 voltage sags alarms (set to 90%)** (fault, instantaneous reclosing)
  - Voltage sag durations were up to 108 ms (electromechanical relay)

- 1300 MWs of load across 20 facilities instantaneously transferred to UPS (not to the diesel generator), but recovered within 20 seconds
  - Customers have been changing settings of facilities which has helped reduce load transferred to long-term back-up generation

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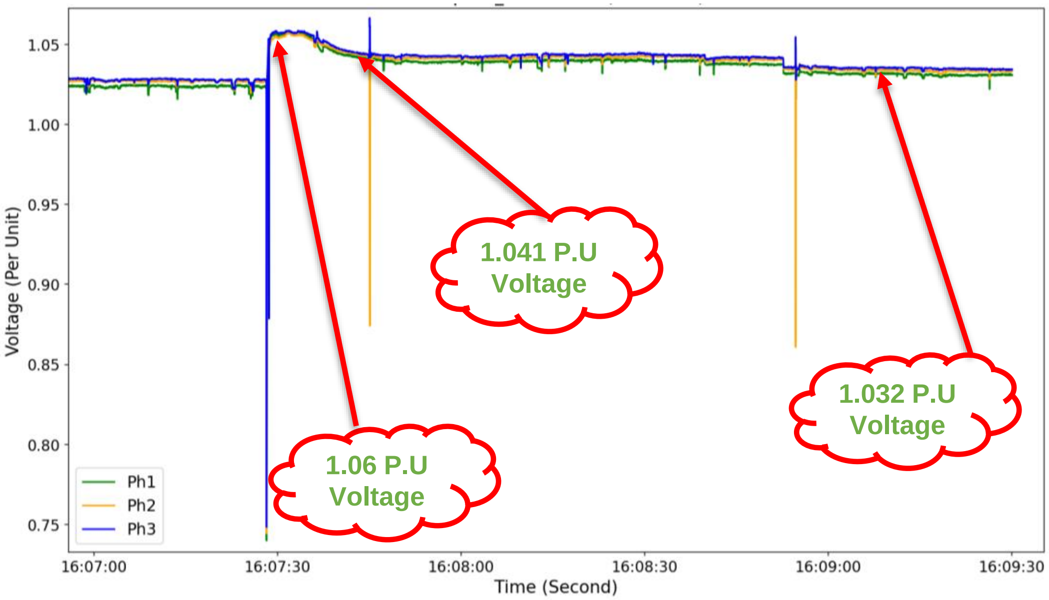
Voltage Observed in Data Center Alley

- Voltage swell (1.06pu) was after the second voltage deviation but went back to 1.041 within 15 sec

- Voltage sag is most severe during the initial 3 phase fault



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Operational Impacts: Substation Voltages

- Voltage swell up to 1.06 pu , with duration less than 1 minute

- Voltage recovered **without** operator intervention

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Event Comparisons

July 10, 2024

- Fault & line lockout in data center alley
- ~1500 MWs load transferred after 3rd reclosing
- 22 substations
- Load ~21,700 MW before transfer

Feb 17, 2025

- Fault & line lockout **outside** data center alley
- ~1700 MWs load transferred after 3rd reclosing
- 18 substations
- Load ~17,470 MW before transfer
- Fewer customers transferred on 7/10/24

June 19, 2025

- Fault & line lockout **outside** of data center alley
- ~1300 MWs of load dropped but recovered over 60 seconds
- 40 substations
- Load ~20,300 MWs before transfer

Key Findings

- Data centers responded with varying degrees of load transfer and recovery
- Customer conversations were critical to deeper understanding of load behavior
  - Revealed transferring methodologies and internal setting requirements
- A subset of data centers rode through the fault without any load transfer, irrespective of their distance from the fault position
- **Impossible** to determine behavior of individual facility without high-resolution POI data

Ongoing Solutions & Future Steps

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Sharing the experiences

- Performing event sharing with numerous industry groups.
- By doing so, we have identified other utilities who have seen or are experiencing similar situations with large non-conforming loads.
- Other examples of these large load transfers have occurred in ERCOT and WECC over the years, however not to the levels we have seen in Northern Virginia.

Future Steps

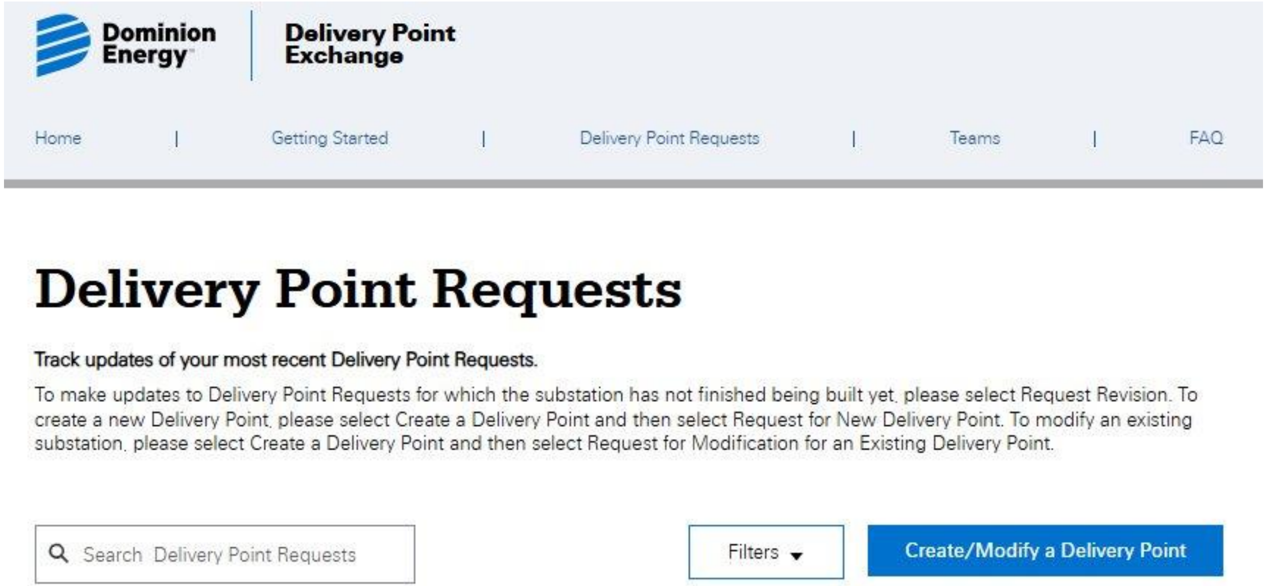
Our follow up actions have been two prong.

1. Revise Facility Interconnection Requirements (FIR) for future connecting customers loads to ensure coordination and understanding of both systems expected responses.

2. Identify existing large load customer which have responded to events on the BES in an unexpected fashion. Educate our staff and customers on the responses of their facilities and the expected coordination for unplanned events on the BES.

Delivery Point Request Portal

- Platform to track all Delivery Point (DP) load interconnection requests
- Live 10/22/24



Facility Interconnection Requirement (FIR) Updates

- Facility Interconnection Requirement (FIR) dictates performance and standards for transmission connected loads and generation
- Updated FIR requires more load information
  - Attachment 2 – Customer Request Form
    - NERC Data Center Information Collection Questionnaire
  - Phasor-domain data center dynamic model
  - October 2025 update included ride-through requirements

Dominion Energy	Dominion Energy Virginia - Electric Transmission Customer Request Form		
Electric Transmission Planning	REVISON 1.0	Effective Date: 09/01/2024	Page 10 of 13

Composite Load Model (CLM)

Total installed load (kW):	kW
Total installed distributed generation (kW):	kW
Total installed low side capacitor bank demand (kVar):	kVar
Total synchronous motor load (kW)	kW
Motor start type	
Motor speed control method	

Data Center Load Information

Total rated load including IT, power distribution and cooling (kW)	kW
Overall Data Center Power Factor (Lead/Lag)	Lead/Lag

Load Percentages

	Summer Daytime	Summer Nighttime	Winter Daytime	Winter Nighttime
Computing/Server Load:				
Lighting Load:				
Power Distribution Losses:				
Cooling load:				

Data Center Cooling System

Forced cooling system:	☐ None
	☐ Computer Room Air Conditioners (CRACs) with internal compressors
	☐ Computer Room Air Handlers (CRAHs) supplied with chilled water.
	☐ Air-Handling Units (AHUs) dedicated to the data center space
	☐ Other:
Cooling system motor driven components:	☐ Single-speed motors that are operated across the line (Motors connected directly to the AC supply)
	☐ Motors controlled by variable/adjustable speed drives or electronically commutated motors (ECMs)
	☐ Other:

Interconnection Study Process

- Establishing a more robust queue process to apply to all delivery point large load requests (100+ MWs)
  - DP requests less than 100 MW and all non-data center load will not be included in this queue and will follow the existing process

- Dominion Energy remains committed to serving all customer load requests, including large load requests, to ensure reliable service both for new and existing customers.

- To be clear, we are not pausing any connections. This process ensures we are matching demand with the generation and transmission infrastructure to meet it. Better aligning customer commitments to PJM processes, as well as a more informed PJM load forecast, mitigates the risk of a constraint on our system.

Ride-Through Recommendations

Short-duration voltage depression timer

- Increase the short-duration voltage depression event detection timer to 80 – 120 milliseconds or more.
  - This duration needs to account for measurement tolerance to ensure that the 50 – 70 ms time needed for circuit breakers to operate is respected
    - For example, if the event detection timer is 80 milliseconds, but the tolerance for that measurement is +/- 20 milliseconds, the event detection could “count” a depression that lasts 60 milliseconds which is within the normal operation time of the circuit breaker. If the tolerance for the timing measurement is +/- 9 milliseconds instead, it would not count a depression lasting 60 milliseconds as an “event.”
  - In general, the higher event detection timer can be within the 80 – 120 millisecond range, the less likely it is that data centers would count normal system

- This is the recommendation for timing allowed before a system event is “counted” before transferring to long-duration back-up generation. The UPS system should be able to tolerate this duration of voltage depression as well.

Under-voltage Pickup Settings & Event Counting Delay

- Where possible, adjust undervoltage pickup relays to ride-through system faults without ***transferring to back-up generation*** in a manner that does not impact low voltage equipment
  - Determine if an overvoltage setting of 90% of nominal voltage can be potentially changed to 85% of nominal voltage
  - Reduces likelihood of transferring to long-term back-up generation
  - UPS can, and likely should, engage at higher voltages

- Add multiple second delay between consecutive utility event counters
  - Between the first voltage depression due to a fault and the second depression from the first high-speed reclosing of the circuit breakers, approximately 300 – 500 millisecond elapses. This should be counted as “one event” rather than two separate events because they will always happen in quick succession.
  - Depending on the number of reclosing attempts necessary, this will reduce the number of “events” counted towards when back-up generation should be started.

Utility Side Recommendations

- Review fault clearing time data to ensure timing you recommend to data centers for ride through is consistent with what you see in the field

- It is also recommended for utilities to replace any electromechanical relays in their system near where data centers are located.
  - *Electromechanical relays can operate variably when compared to digital relays depending on the condition of the electromechanical relays and other factors like temperature within the control enclosure that can lead to timing variably during reclosing cycles and make coordinating with data centers difficult.*
  - *Especially true in areas with large number of data centers clustered together*

- Install high-fidelity monitoring at the appropriate location to discern individual data center behavior

Ongoing Modeling Efforts

- Replicating results from July and February events using full EI MMWG model
  - Model giving more optimistic results than event – working to remedy that
  - Need baseline confidence in model before extrapolating “what-if” scenarios

- Data center load modeling
  - Phasor-domain modeling with CMLD, EPRI EV load models
  - EMT modeling with PNNL generic model

- AI training model
  - Are ramp-rate thresholds needed?
  - Forced oscillations near synchronous generators could excite internal frequency modes within the unit

- Increasing engineers working on this problem due to how the complexity and scale has grown

In Process

- FIR Updates
  - Require high-fidelity time series data capture at the point of interconnection
  - Continued refinement of ride-through requirements
  - Add ramp-rate requirements to address oscillatory behavior
- Continued conversations with data center customers about performance and expectations
- Continued data interrogation
  - Developing processes to help reduce the efforts associated with RCAs
- Dominion Energy Standards
  - Review reclosing standards
  - Review volage control capabilities

Industry Engagement

- Customer Relations
  - Continued understanding of their systems and needs – currently and as they evolve
  - Gathering information from facilities already in service
- Dominion Energy White Paper – published Jan 25
- Partnering with both industry & customers:
  - Evaluate reliability risk
  - Root causes
  - Recommendations
  - Prevention

Large Loads Task Force (LLTF)

Data Center Load Transfer Event
July 10, 2024

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NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Incident Review
Considering Simultaneous Voltage-Sensitive Load Reductions

Primary Takeaways
Operators and planners of the Bulk Electric System (BES) should be aware of the risks and challenges associated with voltage-sensitive large loads that are rapidly being connected to the power system. Specifically, when considering data centers and cryptocurrency mining facilities, entities should be aware of the potential for large amounts of voltage-sensitive load loss during normally cleared faults on the BES. Voltage-sensitive data center-type loads have increased on the system and are predicted to continue growing rapidly. The 2024 NERC *Long-Term Reliability Assessment* (LTRA) documents and discusses this potential growth of data center-type loads. This vignette highlights this load-loss potential based on analysis of a recent event in the Eastern Interconnection and offers some considerations for BES operators, planners, and regulators concerning identifying and mitigating the potential reliability effects and risks presented by these large voltage-sensitive load losses for future operations.

Summary of Incident
A 230 kV transmission line fault led to customer-initiated simultaneous loss of approximately 1,500 MW of voltage-sensitive load that was not anticipated by the BES operators. The electric grid has not historically experienced simultaneous load losses of this magnitude in response to a fault on the system, which has historically been planned for large generation losses but not for such significant simultaneous load losses. Simultaneous large load losses have two effects on the electric system: First, frequency rises on the system as a result of the imbalance between load and generation; second, voltage rises rapidly because less power is flowing through the system. In this incident, the frequency did not rise to a level high enough to cause concern. The voltage also did not rise to levels that posed a reliability risk, but operators did have to take action to reduce the voltage to within normal operating levels. However, as the potential for this type of load loss increases, the risk for frequency and voltage issues also increases. Operators and planners should be aware of this reliability risk and ensure that these load losses do not reach intolerable levels.

Incident Details
At approximately 7:00 p.m. Eastern on July 10, 2024, a lightning arrestor failed on a 230 kV transmission line in the Eastern Interconnection, resulting in a permanent fault that eventually "locked out" the transmission line. The auto-reclosing control on the transmission line was configured for three auto-reclose attempts staggered at each end of the line. This configuration resulted in 6 successive system faults in an 82-second period. The protection system detected these faults and cleared them properly. The shortest fault duration was the initial fault at 42 milliseconds, and the longest fault duration was 66 milliseconds. The voltage magnitudes during the fault ranged from .25 to .40 per unit in the load-loss area.

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Summary

- Events similar in nature but do have some distinct differences.
- Dominion Energy is committed to finding solutions to ensure grid reliability including:
  - Working with industry and regulators
  - Learning from events and sharing what is found
  - Reviewing internal standards
  - Dedicated to finding a solution that works for everyone

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Thank you

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