ERCOT Large Load Loss/Reduction Events 2020-2024

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ESIG Webinar
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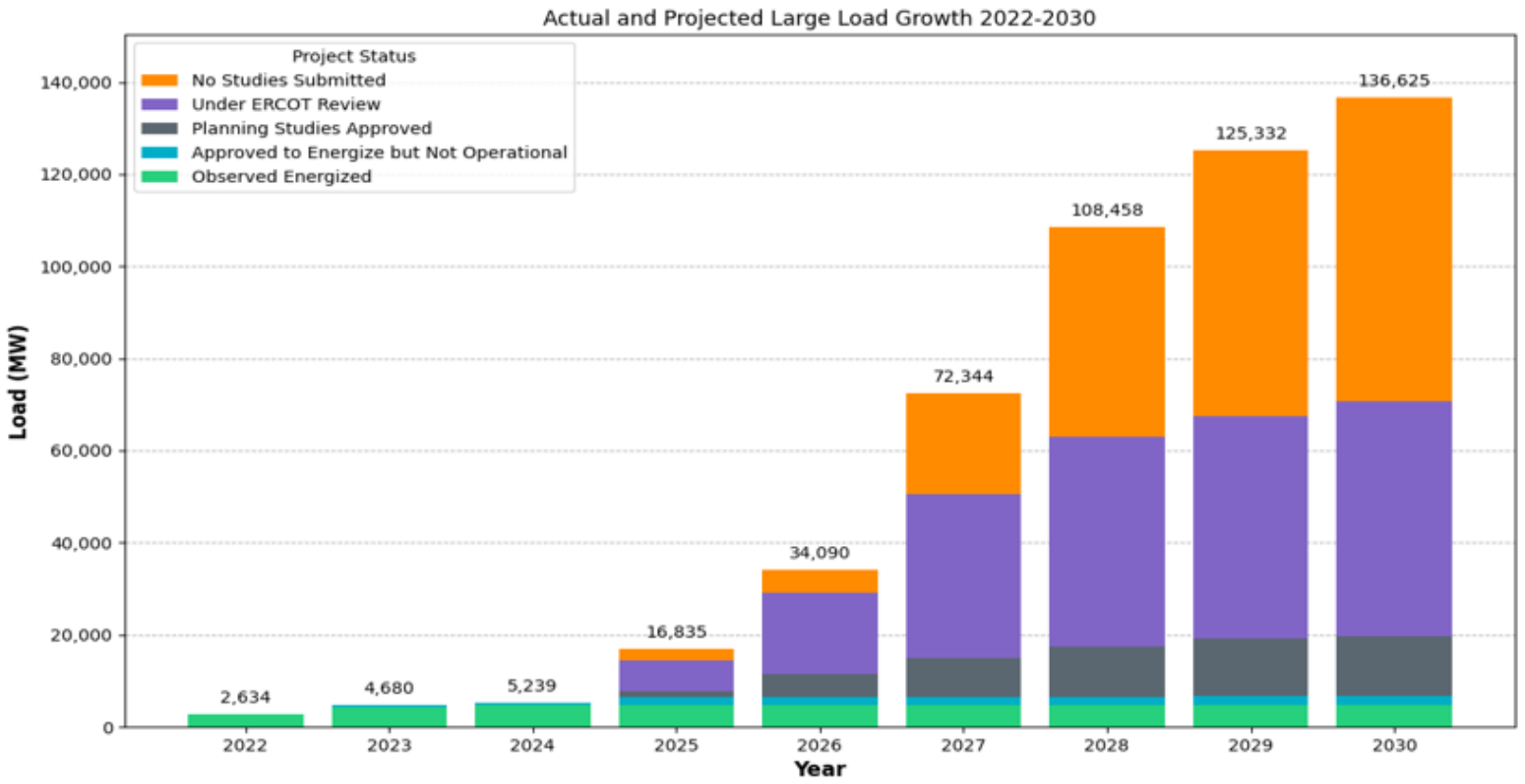
ERCOT Large Load Queue



- **6,779 MW** – Large Load that has received Approval to Energize (A2E)
- **4,616 MW** – Peak non-simultaneous observed consumption of approved loads
- **3,352 MW** – Peak simultaneous observed consumption of approved loads
- **~20,000 MW** – Combined Planning Studies approved, A2E, or operational by 2030
- **85, 508 MW** – ERCOT all-time peak demand record (Aug. 10, 2023)
- Over 90% of approved/energized Large Load is data center/crypto

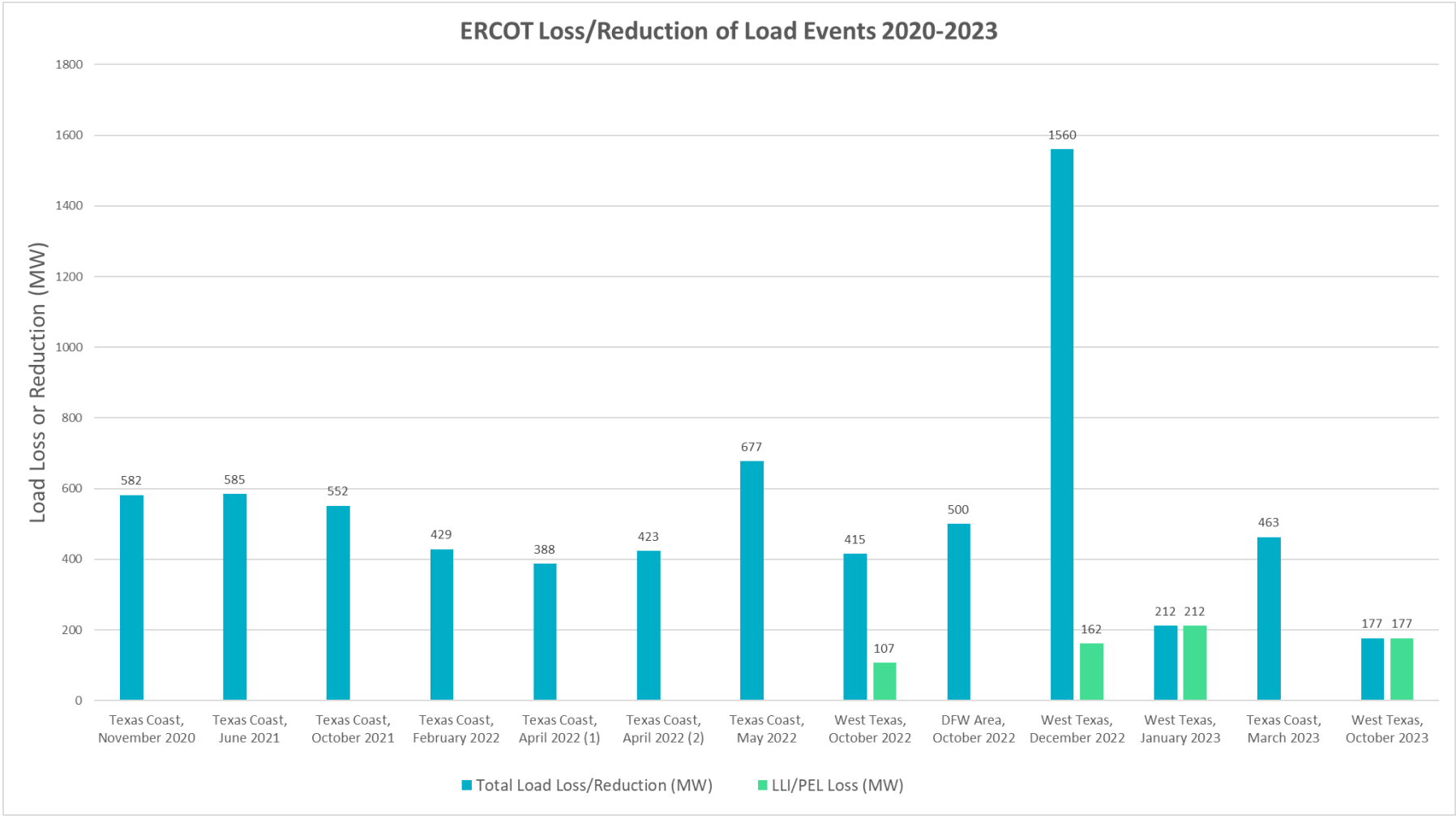
Operational Risks of Large Load Loss Events

- Since 2022, many large electronic-based loads (cryptocurrency and traditional data centers) have connected to the ERCOT Interconnection
- Additional loads have been approved in Planning studies and will connect over the next few years
- ERCOT has observed these loads exhibit voltage-sensitive behavior and immediately reduce consumption during normal voltage disturbances
- Since generation and load must be balanced to maintain system frequency, sudden large loss of load events could adversely affect grid reliability
- Increase of large electronic-based loads could result in larger events leading to system instability

ERCOT Loss/Reduction of Load Events 2020-2023

- 13 events identified by ERCOT Operations that involved system fault followed by significant reduction of one or more large loads
- Reviewed events to distinguish reduction of large loads that have gone through interim Large Load Interconnection (LLI) process since 1/1/2022
  - LLI loads are greater than 25 MW and may include crypto, AI, data center, hydrogen fuel cell loads, or industrial loads and are aggregated into single PI tag for monitoring purposes
  - All LLI loads involved in events are power electronic loads (PEL), and specifically crypto (to our knowledge)
- 8 events involve a single large industrial load on the Texas coast (non-LLI)
- 3 events involve either multiple 3-phase (3PH) faults or significantly delayed fault clearing
  - Events involve wide-spread reduction of consumption of many load types and sizes
- 2 events involve simultaneous loss of both IBR generation and PELs

ERCOT Loss/Reduction of Load Events 2020-2023



- LLI/PEL Load Loss included in Total Load Loss

ERCOT Loss/Reduction of Load Events 2020-2023

West Texas Event – Dec. 7, 2022 @ 03:50 CT – 1560 MW load reduction

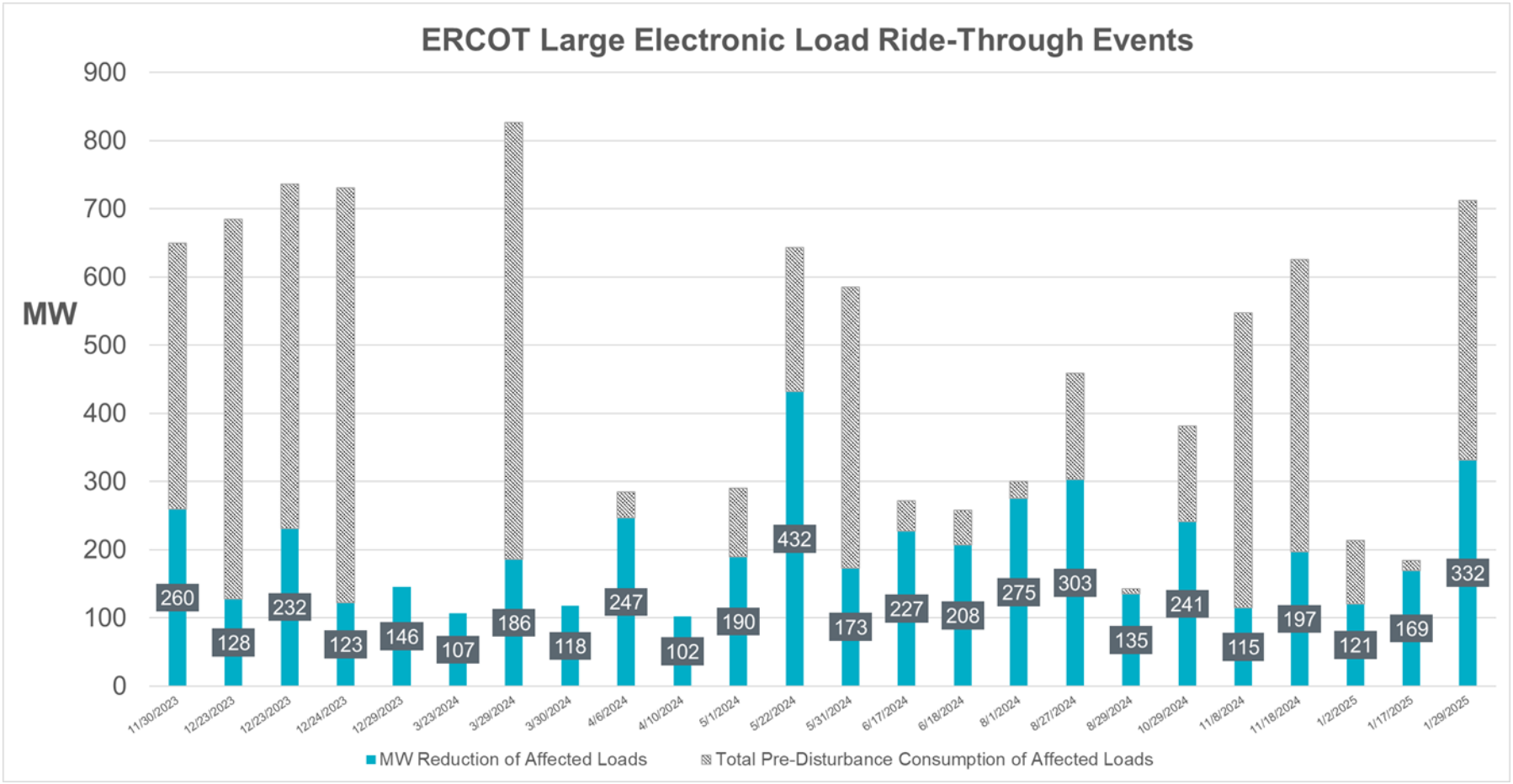
- Multiple Single-Phase Line-to-Ground (SLG) faults and a 3PH ground fault at 138 kV station with delayed 19-cycle clearing due to beaker failure
- Hundreds of loads in Far West Weather zone reduced ~1,560 MW during the event due to extended low voltage period
- 10 large PELs reduced a combined ~162 MW (39% of consumption)
- Largest load reduction from oil and gas production, processing, and delivery facilities (~420 MW from 24 loads)
- System frequency increased to 60.235 Hz and recovered in 12m27s
- 112 MW of thermal generation tripped during event

MW Range of Load Reduction	# of Far West Loads in Range	Total MW Reduction
Greater than 10 MW	41	816
Between 5 MW and 10 MW	46	318
Between 2 and 5 MW	93	314
Between 0 and 2 MW	193	118

Large Power Electronic Load Ride-Through Events November 2023 - Present

- Searched for events in which LLI aggregate tag dropped >100 MW combined with PMU fault flag and system frequency spike
- Collected PMU/DFR data at POIB of large loads from interconnecting TSPs
  - Data availability
  - Confirm fault details and low voltage at POIB during events
  - Confirm MW reduction in consumption of large loads
- 24 events from areas of concentrated large PELs (all crypto loads)
  - 8 events involving 4 loads in Central Texas
    - 890 MW of ERCOT approved consumption
  - 7 events involving 5 loads in 1st pocket in Far West Texas
    - 410 MW of ERCOT approved consumption
  - 4 events involving 3 loads in 2nd pocket in Far West Texas
    - 345 MW of ERCOT approved consumption
    - All consequential loss – loss of line connecting loads during fault
  - 4 events involving 7 loads in multiple pockets in Far West Texas
    - 1,785 MW of ERCOT approved consumption
  - 1 event involving single load in North load zone
    - 264 MW of ERCOT approved consumption

Large Power Electronic Load Ride-Through Events November 2023 - Present

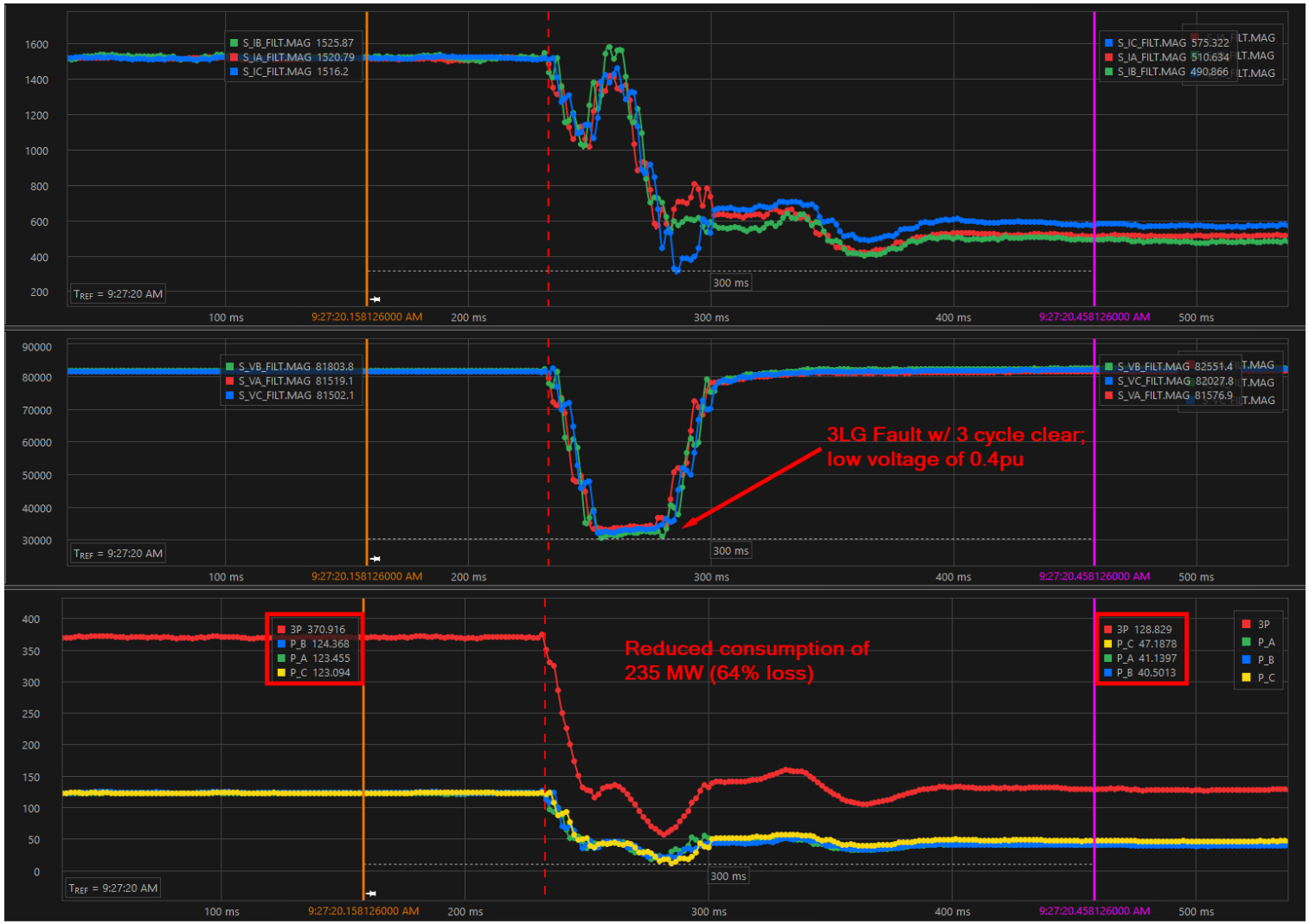


Central Texas Events

Date	Fault Details	Load Zone	Load	Load Type	ERCOT Approved MW	Low Voltage at POI (pu & kV)	Pre-Disturbance Consumption (MW)	Post-Disturbance Consumption (MW)	Total Load Reduction (MW)	% Load Reduction
11/30/2023	345 kV line AG Fault 4 cycle clear	South	LOAD A	Crypto	345	0.489 (138 kV)(Aφ)	248	125.6	122.4	49.35
			LOAD B	Crypto	390	0.489 (138 kV)(Aφ)	353.5	239.3	114.2	32.31
			LOAD C	Crypto	65	0.489 (138 kV)(Aφ)	47.9	24.7	23.2	48.43
			TOTAL		800		649.4		259.8	40.01
12/23/2023	345 kV line AG Fault 4 cycle clear	South	LOAD A	Crypto	345	0.486 (138 kV)(Aφ)	321.8	169.9	151.9	47.20
			LOAD B	Crypto	390	0.486 (138 kV)(Aφ)	365.1	305	60.1	16.46
			LOAD C	Crypto	65	0.540 (138 kV)(Aφ)	49.5	29.9	19.6	39.60
			TOTAL		800		736.4		231.6	31.45
12/23/2023	345 kV line CG Fault 3 cycle clear	South	LOAD A	Crypto	345	0.844 (138 kV)(Cφ)	281.7	205.8	75.9	26.94
			LOAD B	Crypto	390	0.844 (138 kV)(Cφ)	354.6	312.3	42.3	11.93
			LOAD C	Crypto	65	0.844 (138 kV)(Cφ)	48.1	38.5	9.6	19.96
			TOTAL		800		684.4		127.8	18.67
12/24/2023	345 kV line CG Fault 3 cycle clear	South	LOAD A	Crypto	345	0.523 (138 kV)(Cφ)	314.5	235.3	79.2	25.18
			LOAD B	Crypto	390	0.523 (138 kV)(Cφ)	367.2	332.4	34.8	9.48
			LOAD C	Crypto	65	0.523 (138 kV)(Cφ)	48.8	40.1	8.7	17.83
			TOTAL		800		730.5		122.7	16.80
3/29/2024	345 kV line CG Fault 3 cycle clear	South	LOAD A	Crypto	345	0.555 (138 kV)(Cφ)	319.7	225.8	93.9	29.37
			LOAD B	Crypto	390	0.559 (138 kV)(Cφ)	364.1	302.8	61.3	16.84
			LOAD C	Crypto	65	0.559 (138 kV)(Cφ)	47.5	35.9	11.6	24.42
			LOAD D	Crypto	90	0.572 (138 kV)(Cφ)	95.1	76	19.1	20.08
			TOTAL		890		826.4		185.9	22.50
5/22/2024	345 kV lines & 3LG Faults	South	LOAD A	Crypto	345	0.54 (138 kV)(PS)	230	65.4	164.6	71.57
			LOAD B	Crypto	390	0.54 (138 kV)(PS)	310.2	135.1	175.1	56.45
			LOAD C	Crypto	65	0.54 (138 kV)(PS)	37.4	10.6	26.8	71.66
			LOAD D	Crypto	90	0.00 (138 kV)	65.4	0	65.4	100.00
			TOTAL		890		643		431.9	67.17
5/31/2024	138 kV line AG Fault 4 cycle clear	South	LOAD A	Crypto	345	0.407 (138 kV)(Aφ)	212.1	117.1	95	44.79
			LOAD B	Crypto	390	0.403 (138 kV)(Aφ)	337.7	268	69.7	20.64
			LOAD C	Crypto	65	0.401 (138 kV)(Aφ)	35.1	26.5	8.6	24.50
			TOTAL		800		584.9		173.3	29.63
8/27/2024	138 kV line 3LG Fault 3 cycle clear	South	LOAD A	Crypto	345	0.405 (138 kV)(PS)	91.8	24.3	67.5	73.53
			LOAD B	Crypto	390	0.405 (138 kV)(PS)	367.2	131.9	235.3	64.08
			TOTAL		735		459		302.8	65.97

- 2 events were 3PH faults and rest were SLG faults
- Reductions range from 17% - 67% of pre-disturbance consumption
- % reduction larger for 3LG faults than for SLG faults

Central Texas LOAD B – 8/27/2024 Event

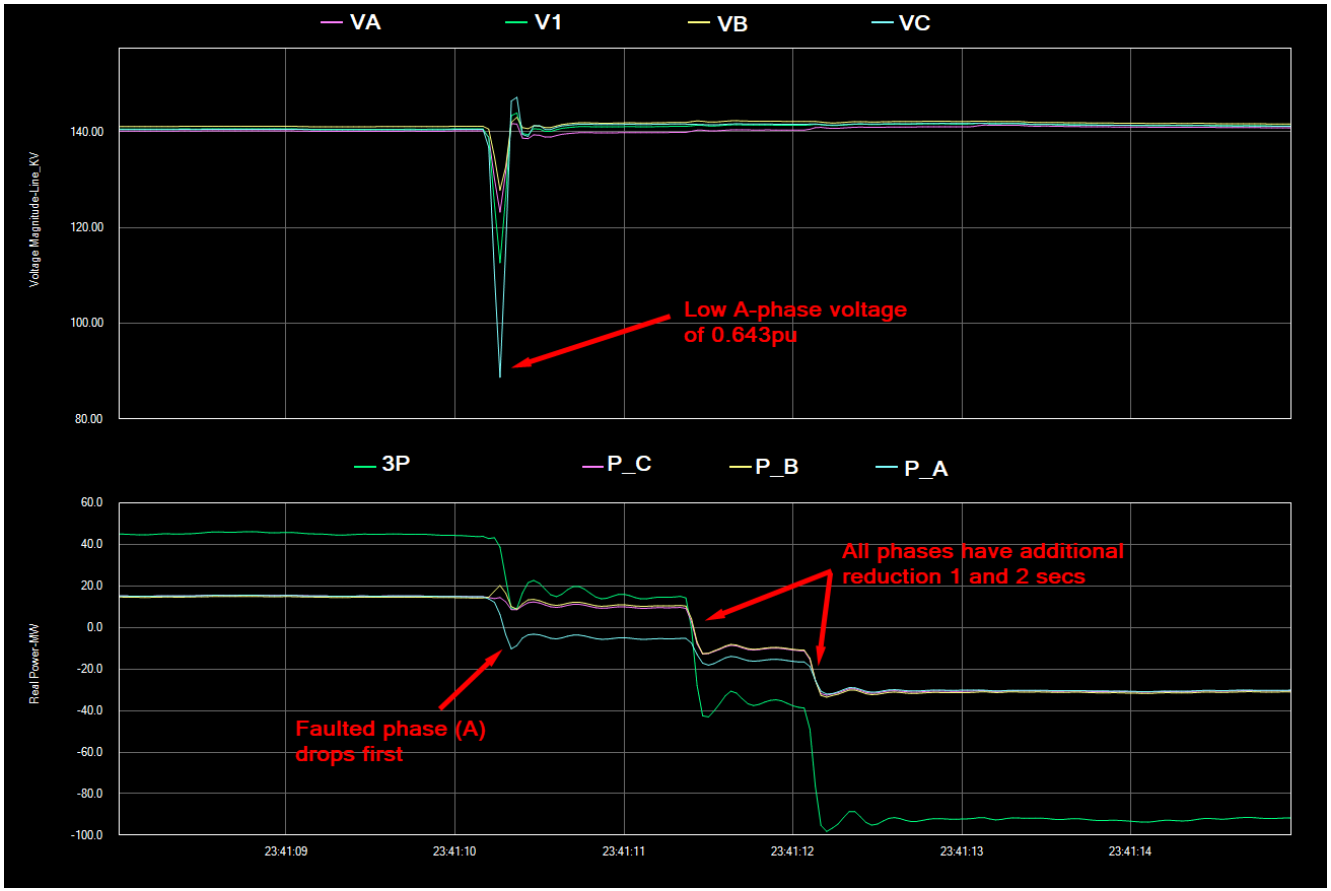


Far West Texas Events (1st Pocket)

Date	Fault Details	Load Zone	Load	Load Type	ERCOT Approved MW	Low Voltage at POI (pu & kV)	Pre-Disturbance Consumption (MW)	Post-Disturbance Consumption (MW)	Total Load Reduction (MW)	% Load Reduction
12/29/2023	138 kV line Unknown fault type & clearing time	West	LOAD F	Crypto	80	0.00 (138 kV)	72.7	0	72.7	100.00
			LOAD H	Crypto	80	0.00 (138 kV)	73.1	0	73.1	100.00
			TOTAL		160		145.8		145.8	100.00
4/6/2024	138 kV line AG Fault 3 cycle clear	West	LOAD E	Crypto	130	0.356 (138 kV)(Aϕ)	53.4	12	41.4	77.53
			LOAD F	Crypto	80	0.804 (138 kV)(PS)	69.5	0	69.5	100.00
			LOAD G	Crypto	80	0.804 (138 kV)(PS)	65.1	0	65.1	100.00
			LOAD H	Crypto	80	0.804 (138 kV)(PS)	63	0	63	100.00
			LOAD I	Crypto	40	0.804 (138 kV)(PS)	33.4	25.5	7.9	23.65
			TOTAL		410		284.4		246.9	86.81
5/1/2024	138 kV line AG Fault 3 cycle clear	West	LOAD E	Crypto	130	0.398 (138 kV)(Aϕ)	55.5	12.5	43	77.48
			LOAD F	Crypto	80	0.866 (138 kV)(PS)	66.8	61.3	5.5	8.23
			LOAD G	Crypto	80	0.866 (138 kV)(PS)	67.1	0	67.1	100.00
			LOAD H	Crypto	80	0.866 (138 kV)(PS)	67.2	0	67.2	100.00
			LOAD I	Crypto	40	0.866 (138 kV)(PS)	33.5	26.8	6.7	20.00
			TOTAL		410		290.1		189.5	65.32
6/17/2024	138 kV line AG Fault 3 cycle clear	West	LOAD E	Crypto	130	0.384 (138 kV)(Aϕ)	52.9	20	32.9	62.19
			LOAD F	Crypto	80	0.846 (138 kV)(PS)	63.3	0	63.3	100.00
			LOAD G	Crypto	80	0.843 (138 kV)(PS)	60.5	0	60.5	100.00
			LOAD H	Crypto	80	0.846 (138 kV)(PS)	62.7	0	62.7	100.00
			LOAD I	Crypto	40	0.843 (138 kV)(PS)	32.6	25	7.6	23.31
			TOTAL		410		272		227	83.46
6/18/2024	138 kV line BG Fault 3 cycle	West	LOAD E	Crypto	130	0.683 (138 kV)(Bϕ)	31.4	23.9	7.5	23.89
			LOAD F	Crypto	80	0.010 (138 kV)(PS)	62.7	0	62.7	100.00
			LOAD G	Crypto	80	0.717 (138 kV)(PS)	67.2	0	67.2	100.00
			LOAD H	Crypto	80	0.010 (138 kV)(PS)	62.1	0	62.1	100.00
			LOAD I	Crypto	40	0.717 (138 kV)(PS)	34.1	26.1	8	23.46
			TOTAL		410		257.5		207.5	80.58
8/1/2024	138 kV line BG and BC Faults; 3-4 cycle clearing times	West	LOAD E	Crypto	130	0.380 (138kV)(Bϕ)	80.2	0	80.2	100.00
			LOAD F	Crypto	80	0.716 (138 kV)(PS)	63.6	0	63.6	100.00
			LOAD G	Crypto	80	0.756 (138 kV)(PS)	63.2	0	63.2	100.00
			LOAD H	Crypto	80	0.716 (138 kV)(PS)	61.3	0	61.3	100.00
			LOAD I	Crypto	40	0.756 (138 kV)(PS)	31.9	25	6.9	21.63
			TOTAL		410		300.2		275.2	91.67
10/29/2024	138 kV line AG Fault 3 cycle clear	West	LOAD E	Crypto	130	0.305 (138 kV)(Aφ)	110.8	87.4	23.4	21.12
			LOAD F	Crypto	80	0.643 (138 kV)(Aφ)	68.7	0	68.7	100.00
			LOAD G	Crypto	80	0.628 (138 kV)(Aφ)	68.4	0	68.4	100.00
			LOAD H	Crypto	80	0.643 (138 kV)(Aφ)	67.8	0	67.8	100.00
			LOAD I	Crypto	40	0.628 (138 kV)(Aφ)	34.4	26.7	7.7	22.38
			LOAD J	Crypto	36	0.490 (138 kV)(Aφ)	31.5	26.9	4.6	14.60
			TOTAL		446		381.6		240.6	63.05

- All 138 kV SLG faults with exception of one line-to-line fault
- Loads F,G, and H are particularly sensitive to SLG faults (100% reduction)
- Load E has improved ride-though performance for SLG faults

Far West LOAD F and LOAD H – 10/29/2024 Event



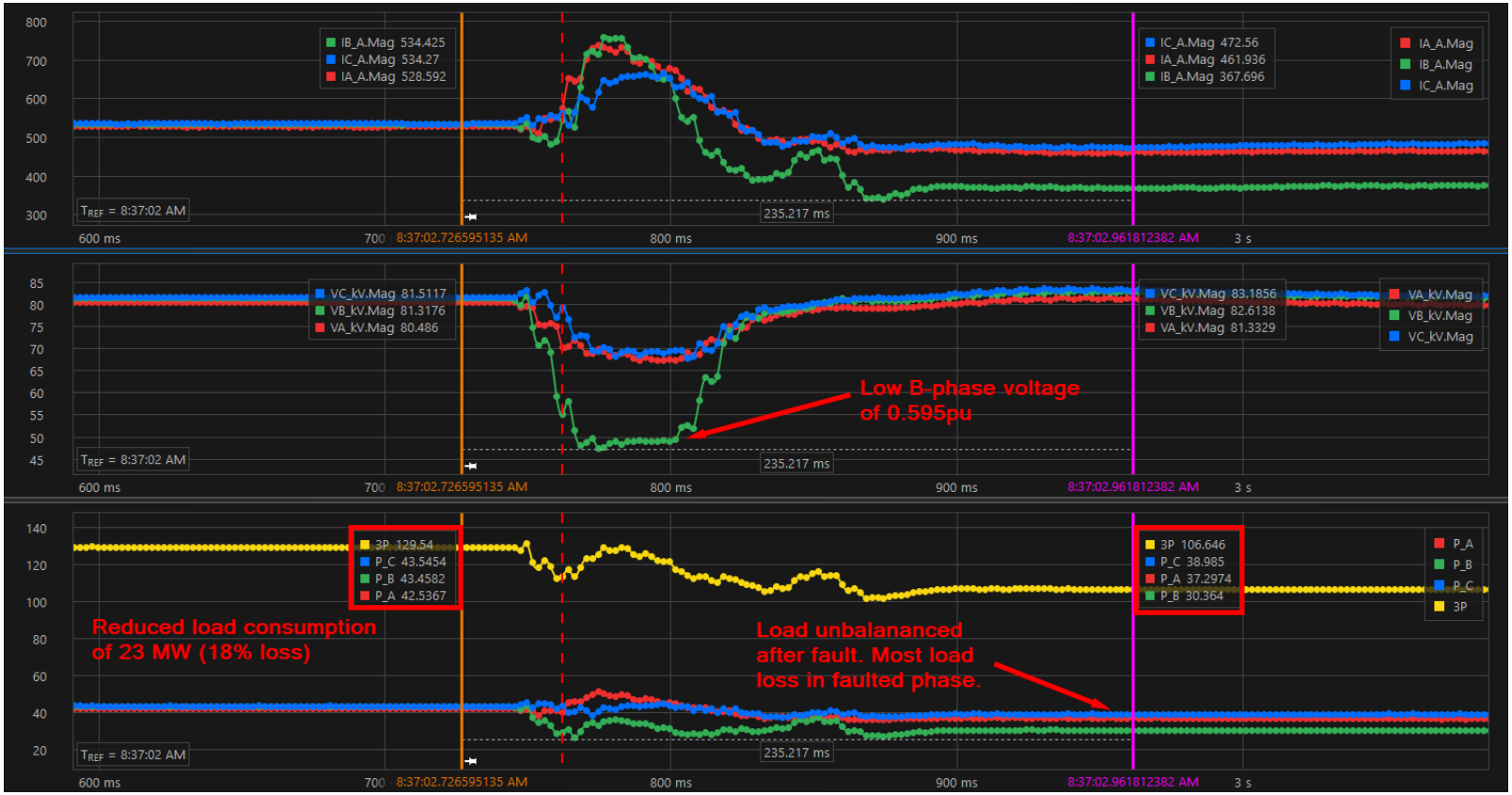
- PMU data at POI towards two co-located sites; Change in line MW flow corresponds to reductions seen in load telemetry (~136 MW and 100% of pre-disturbance consumption)
- Similar performance seen for multiple events for Loads F,G, and H
- Possible phase balance protection within facilities?

Far West Texas Events (Multiple Pockets)

Date	Fault Type	Load Zone	Load	Load Type	ERCOT Approved MW	Low Voltage at POI (pu & kV)	Pre-Disturbance Consumption (MW)	Post-Disturbance Consumption (MW)	Total Load Reduction (MW)	% Load Reduction
11/8/2024	345 kV; AG Fault; 4 cycle clear	West	LOAD K	Crypto	207	0.08 (345 kV)(Aϕ)	190.9	105.6	85.3	44.68
			LOAD L	Crypto	345	0.598 (138kV)(Aϕ)	129.7	118.5	11.2	8.64
			LOAD E	Crypto	130	0.663 (138kV)(Aϕ)	110	100.4	9.6	8.73
			LOAD M	Crypto	324	0.627 (138kV)(Aϕ)	80.5	73.4	7.1	8.82
			LOAD N	N/A	10	N/A	8	6.3	1.7	21.25
			LOAD O	Crypto	143	0.589 (138kV)(Aϕ)	27.8	27.4	0.4	1.44
			TOTAL		1159		546.9		115.3	21.08
11/18/2024	345 kV: BG Fault; 4 cycle clear	West	LOAD K	Crypto	207	0.079 (345 kV)(Bϕ)	194	108.5	85.5	44.07
			LOAD G	Crypto	80	0.728 (138kV)(Bϕ)	67.6	0	67.6	100.00
			LOAD L	Crypto	345	0.595 (138kV)(Bϕ)	129.7	107	22.7	17.50
			LOAD E	Crypto	130	0.652 (138kV)(Bϕ)	114	102.4	11.6	10.18
			LOAD M	Crypto	324	0.632 (138kV)(Bϕ)	86.2	79.6	6.6	7.66
			LOAD N	N/A	10	N/A	5.8	4.6	1.2	20.69
			LOAD O	Crypto	143	0.589 (138kV)(Bϕ)	28.2	26.6	1.6	5.67
			TOTAL		1239		625.5		196.8	31.46
1/17/2025	138 kV: AG Fault; 4 cycle clear	West	LOAD M	Crypto	324	0.09 (138 kV)(Aφ)	131.7	0.7	131	99.47
			LOAD R	Crypto		0.11 (138 kV)(Aφ)	23.7	0.1	23.6	99.58
			LOAD S	Crypto		0.11 (138 kV)(Aφ)	13.1	0.8	12.3	93.89
			LOAD P	Crypto	42	N/A	15.4	13.1	2.3	14.94
			TOTAL		366		183.9		169.2	92.01
1/29/2025	345 kV; AG Fault; 4 cycle clear	West	LOAD K	Crypto	207		196.7	125.8	70.9	36.04
			LOAD G	Crypto	80	0.682 (138 kV)(Aϕ)	67.9	0	67.9	100.00
			LOAD F	Crypto	80	0.678 (138kV)(Aϕ)	62.5	0	62.5	100.00
			LOAD H	Crypto	80	0.678 (138kV)(Aϕ)	63.8	0	63.8	100.00
			LOAD Q	Crypto	234	0.631 (138 kV)(Aφ)	155.2	119.4	35.8	23.07
			LOAD L	Crypto	345	0.603 (138 kV)(Aφ)	136.5	111	25.5	18.68
			LOAD P	Crypto	42	0.654 (138 kV)(Aφ)	20.2	16.7	3.5	17.33
			LOAD N	N/A	10		9	7.3	1.7	18.89
			TOTAL		1078		711.8		331.6	46.59

- 345 kV faults in West Texas affecting larger area and number of loads
- Events were all SLG faults; likely larger reductions for 3LG faults
- Multiple loads show reduced active power in faulted phase only
- Some affected loads involved in 2022-2023 events and had larger reductions
- Pre-disturbance load consumption for **all LLI loads in West Texas** was between1,300 and 1,400 MW for all events (table above is just affected loads that reduced consumption)

Far West LOAD L – 11/18/2024 Event



- DFR data directly monitoring load
- Load balanced before fault and unbalanced after fault
- Majority of load loss in faulted phase

Key Observations

- Large variance in % of reduction with similar voltage dips at POI
  - Some large PELs more sensitive than others
  - Possible facility protection systems not visible to ERCOT nor included in dynamic models
  - Different facility electrical designs (transformer windings)
- SLG faults causing significant reductions for shallow positive sequence voltage dips as high as 0.85pu
  - Faulted phase likely reducing below ~0.7pu causing load reductions
  - Single-phase high-resolution data required for analysis
- ~2,042 MW of operational large load in Far West Texas weather zone
  - Potential for reductions of ~1000 MW or greater in Far West Texas with 3PH fault on 345 kV during high consumption
  - Additional ~3,500 MW in Far West Texas has been approved or is in Planning review
- Other weaker grid areas may see similar events with projected large load growth

Key Takeaways and Next Steps

- Working with NERC Event Analysis team on ERCOT events report
- ERCOT Operations to continue monitoring and tracking large load ride-through events
- Operations to continue working with TSPs to retrieve event data and ensure proper Disturbance Monitoring Equipment is in place
- Establish communication between ERCOT, TSPs, and load owners to evaluate ride-through performance of large PELs
- Challenges and issues to be addressed
  - Determine actual ride-through capabilities of each type of large load
  - Verify and validate load models for accurate representation of ride-through capabilities
  - Develop reliability criteria through studies
  - Examine potential ways to mitigate and/or minimize large load loss during fault events
  - Difficulty performing event analysis without formal RFI process for loads

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Questions?