

Reliability Issues Observed with Large - Loads: oscillations...

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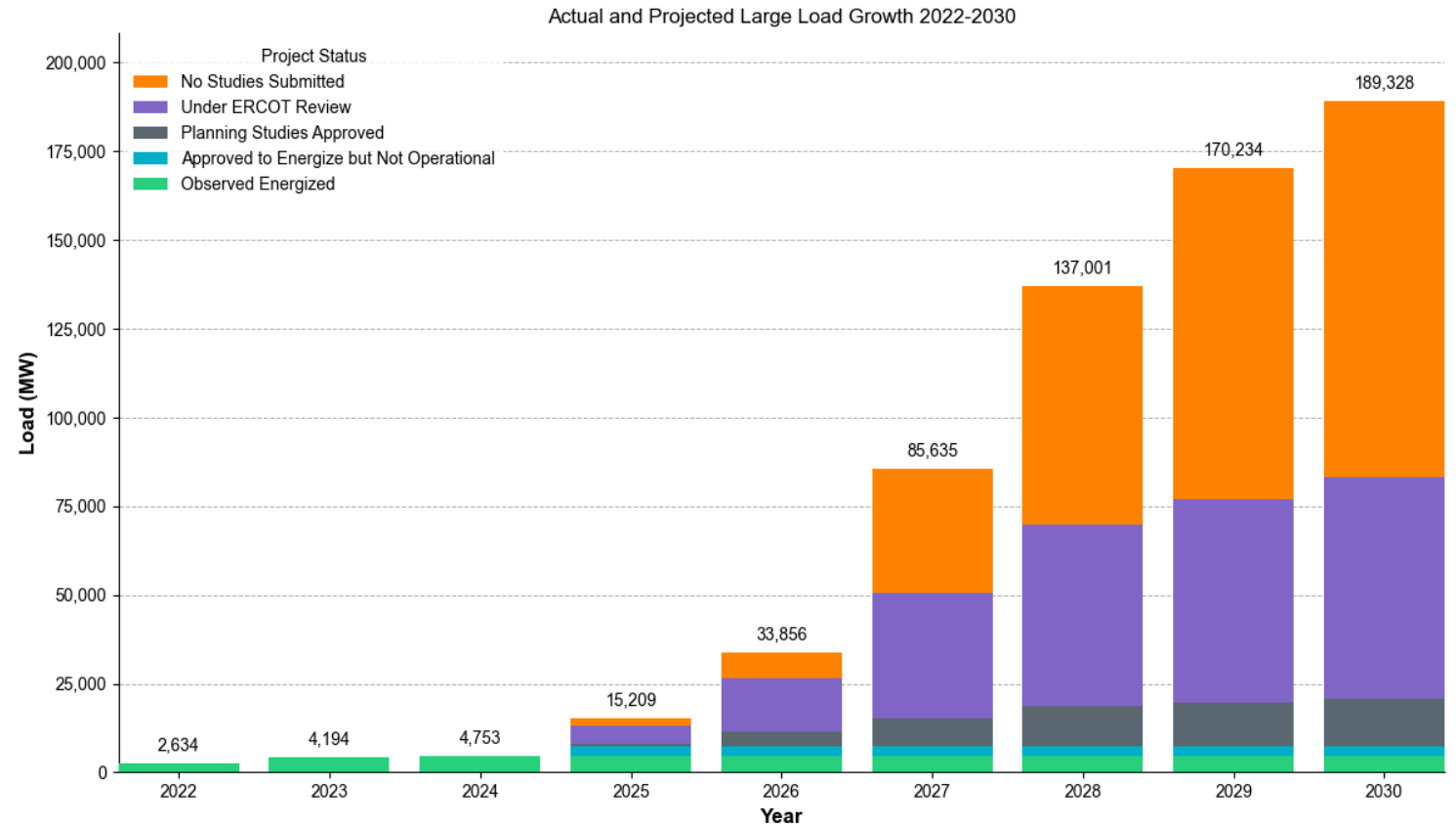
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ERCOT Large Load (LL) Queue

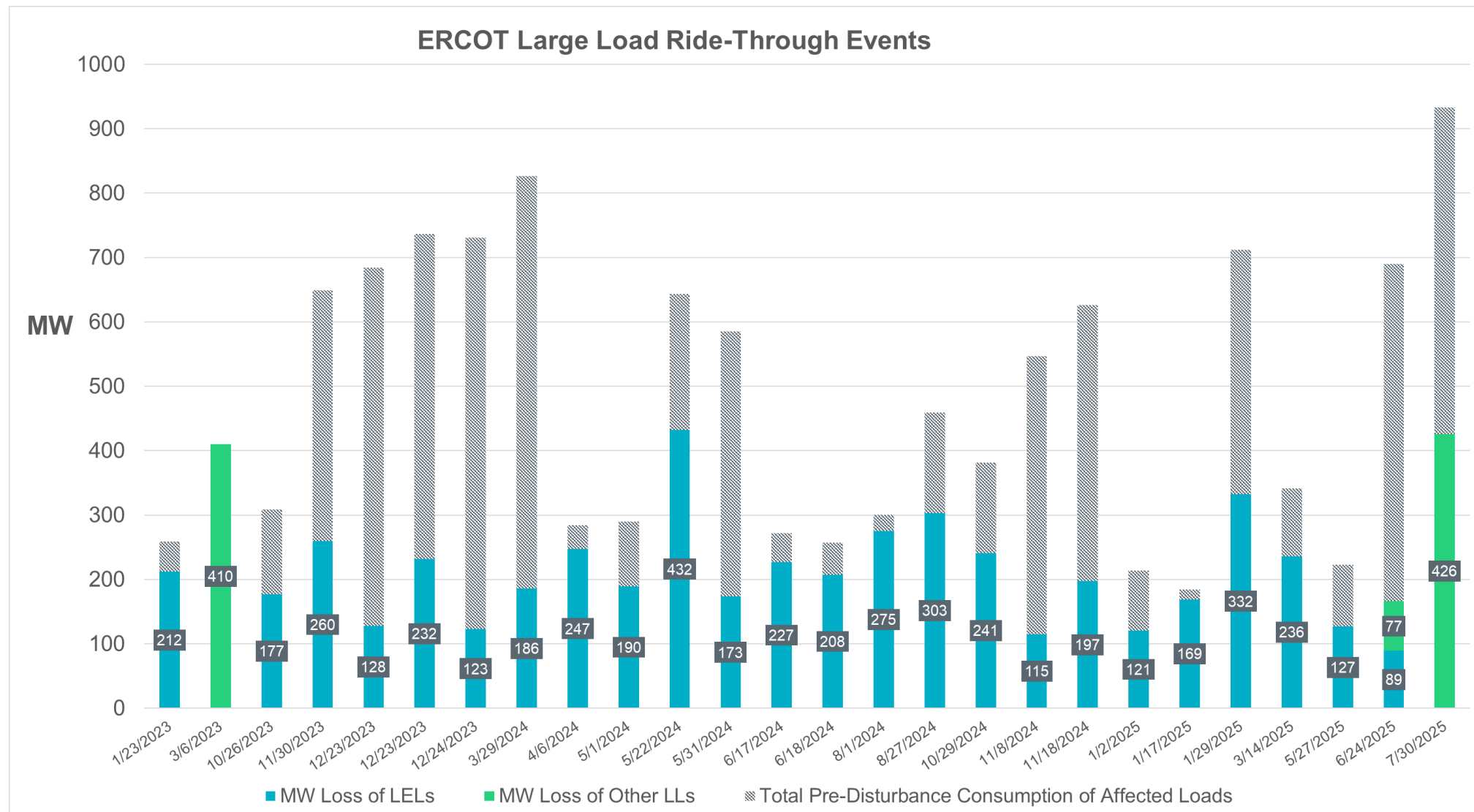
- In the ERCOT Interconnection, a large load is defined as 75 MW or larger
- Since 2022, many LLs have connected to the ERCOT
- Additional LLs have been approved in Planning studies and will connect over the next few years
- Over 90% of approved/energized LL is data center/crypto



Project Status	2022	2023	2024	2025	2026	2027	2028	2029	2030
No Studies Submitted	0	0	0	2,072	7,208	35,054	67,332	93,400	106,267
Under ERCOT Review	0	0	0	5,192	15,062	35,198	50,966	56,981	62,388
Planning Studies Approved	0	0	0	443	4,084	7,881	11,201	12,351	13,171
Approved to Energize but Not Operational	0	83	137	2,886	2,886	2,886	2,886	2,886	2,886
Observed Energized	2,634	4,111	4,616	4,616	4,616	4,616	4,616	4,616	4,616
Total (MW)	2,634	4,194	4,753	15,209	33,856	85,635	137,001	170,234	189,328

Large Load Ride-Through Events

Since Nov. 2023 – Aug. 2025



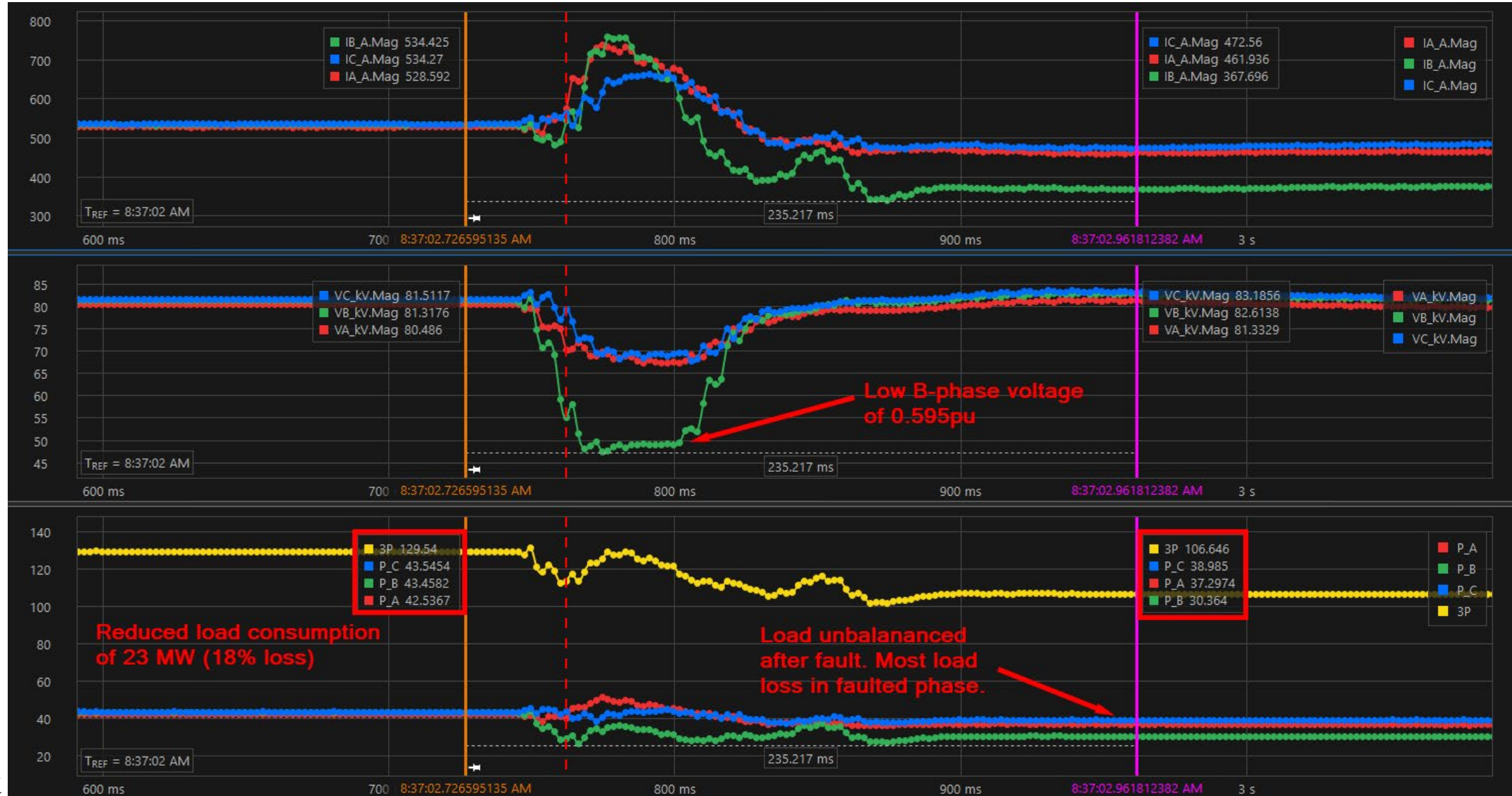
Partial Tripping

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

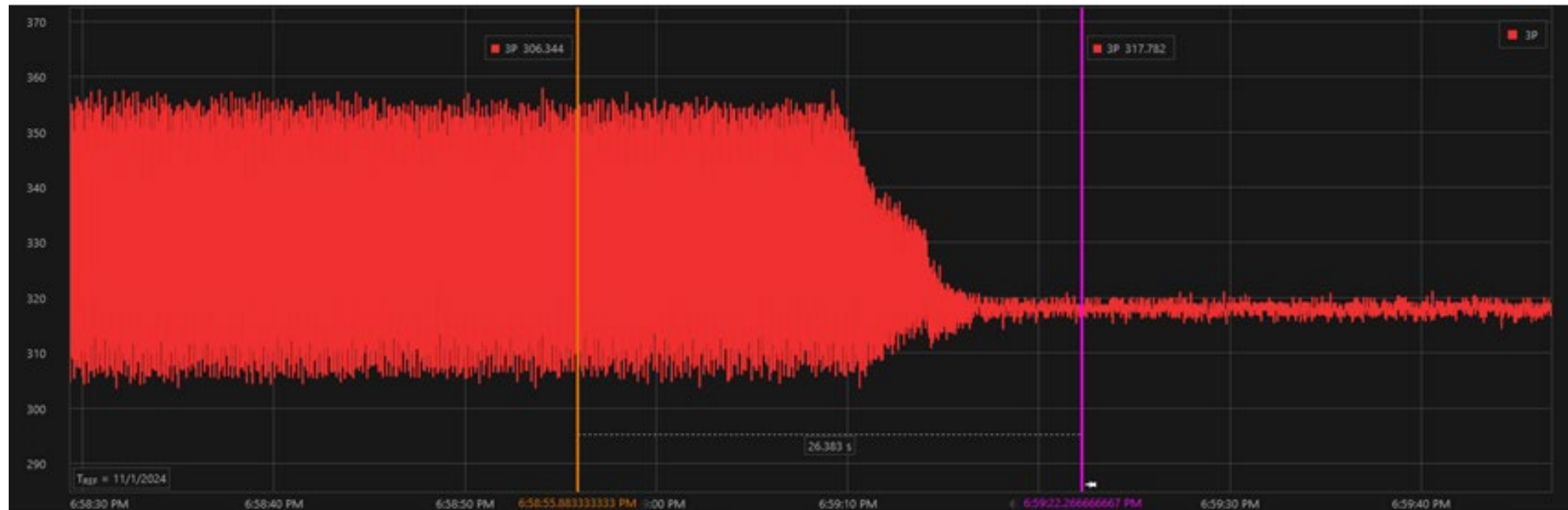
Partial Tripping

Real-world example: Far West LOAD L – 11/18/2024 Event



Large Load Oscillation

- July 24, 2024: ~40 MW oscillations observed in large load telemetry.
- Oct. 25, 2024: ~50 MW peak-to-peak oscillation at ~23 Hz



Challenges Observed with Large Loads

- **Sensitivity of Large Loads to Voltage Dips**
 - Large electrical loads can be highly sensitive to voltage dips or sags.
 - Their response varies significantly — for the same voltage dip, some loads may reduce power by 10%, while others may drop by as much as 40%.
 - Maintaining a proper balance between generation and load is critical to keep system frequency stable during such events.
- **As large loads continue to grow in the grid, their sensitivity to disturbances could lead to:**
 - Partial tripping of facilities, where only part of the load disconnects
 - Forced oscillations that could destabilize the power system
 - Abrupt increases in power demand, stressing generation and transmission systems

Need for EMT simulation

- **Positive-sequence models are based on the following assumptions:**
 - The power system is perfectly balanced (three phases of equal magnitude, 120° apart).
 - All components are represented at the fundamental frequency (50 or 60 Hz).
 - System states are expressed using phasors (magnitude and angle), assuming sinusoidal conditions.
 - Fast control dynamics, such as phase-locked loops (PLLs) or inner current controllers, are not represented.
- **They do not simulate unbalanced conditions, harmonics, or sub-synchronous oscillations.**

Replicate Real-World Events in EMT Simulation

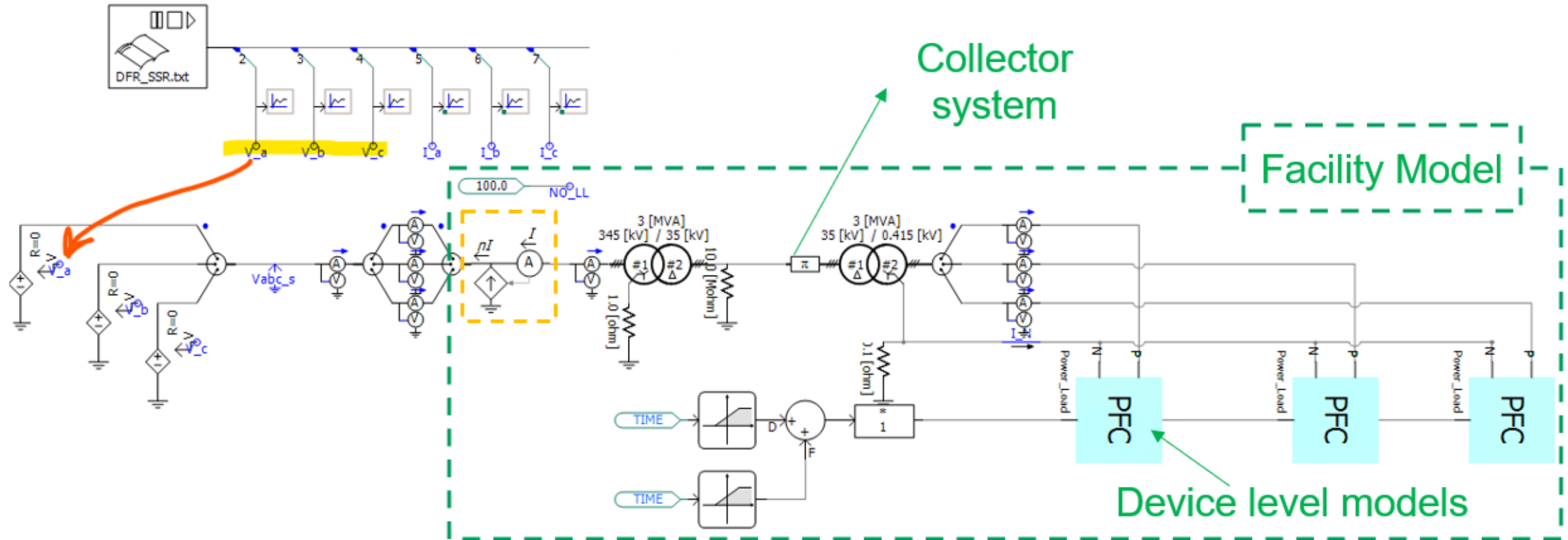
- **Purpose of Actual Event Replication (e.g., Oscillation):**
- Validate model performance against real-world system behavior
- Confirm accuracy of model parameters using measured event data
- Evaluate large-load (LL) model response during actual system disturbances
- Identify the cause of observed oscillations (root cause analysis)
- Assess transmission system stability under realistic operating conditions

Replicate Real-World Events in Simulation

- Digital Fault Recorder (DFR) data at POI: 20 sample per cycle

!time	VakV	VbkV	VckV	IakA	IbkA	IckA
0.000000	262.1625	-237.2089	-25.26951	0.6523207	-0.7850165	0.1206172
0.000833	284.9644	-170.9512	-113.6323	0.8101403	-0.6585709	-0.1468383
0.001667	283.2754	-89.4961	-193.9072	0.8311829	-0.4583654	-0.3723401
0.002500	253.1141	-3.296802	-249.7175	0.799619	-0.2054742	-0.5978419
0.003333	195.0836	85.79726	-281.2238	0.6733633	0.07375995	-0.7604129
0.004167	117.026	170.5492	-287.5412	0.5628896	0.2845027	-0.8180994
0.005000	32.4134	234.3945	-266.1346	0.2630326	0.5268568	-0.7971225
0.005833	-56.70334	274.2376	-216.5613	0.04734586	0.6743766	-0.7289475
0.006667	-143.3267	288.0681	-143.6901	-0.1420376	0.7375995	-0.6030861
0.007500	-214.9097	276.9716	-61.48377	-0.4471554	0.7850165	-0.3513632
0.008333	-261.7603	236.8069	25.30974	-0.6523207	0.7270623	-0.06293072
0.009167	-285.6883	170.0667	115.2418	-0.7417518	0.621691	0.09964031
0.010000	-283.3558	89.4157	193.9475	-0.7470125	0.4320226	0.3356305
0.010833	-252.6717	3.658646	249.1944	-0.7101879	0.1264456	0.5873534
0.011667	-194.8021	-86.36013	281.8274	-0.6365388	-0.1211771	0.7499244
0.012500	-116.4228	-171.2729	288.0241	-0.4787193	-0.2792341	0.7551686
0.013333	-32.49383	-234.7966	266.6979	-0.226208	-0.4952454	0.7079706
0.014167	55.61754	-273.715	216.9637	0.05786716	-0.6427652	0.5925977
0.015000	144.0908	-288.5506	143.328	0.226208	-0.7007195	0.4877131
0.015833	216.7194	-277.7354	60.79972	0.4103308	-0.6849138	0.2831883
0.016667	262.8461	-236.9275	-26.07427	0.5786716	-0.6111539	0.005244226

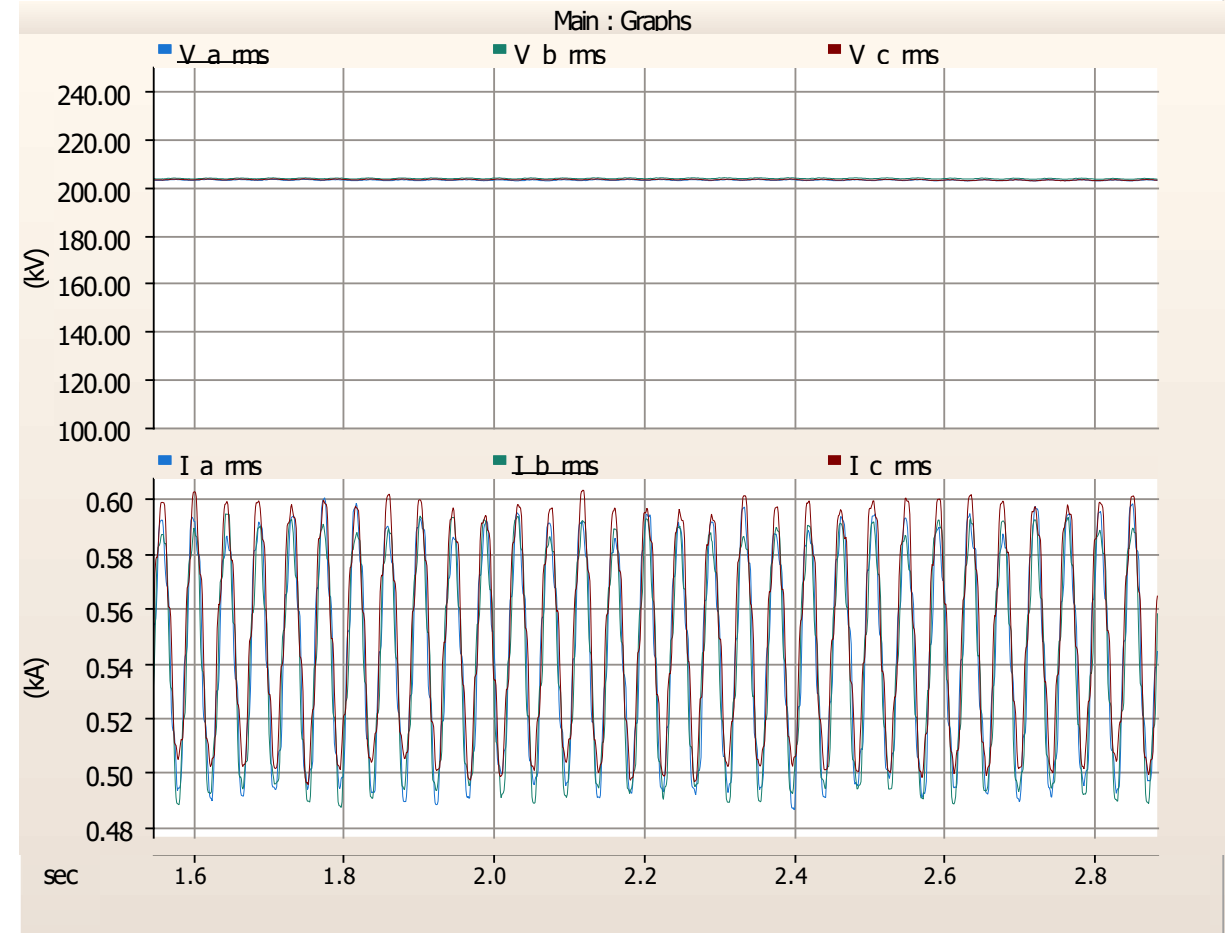
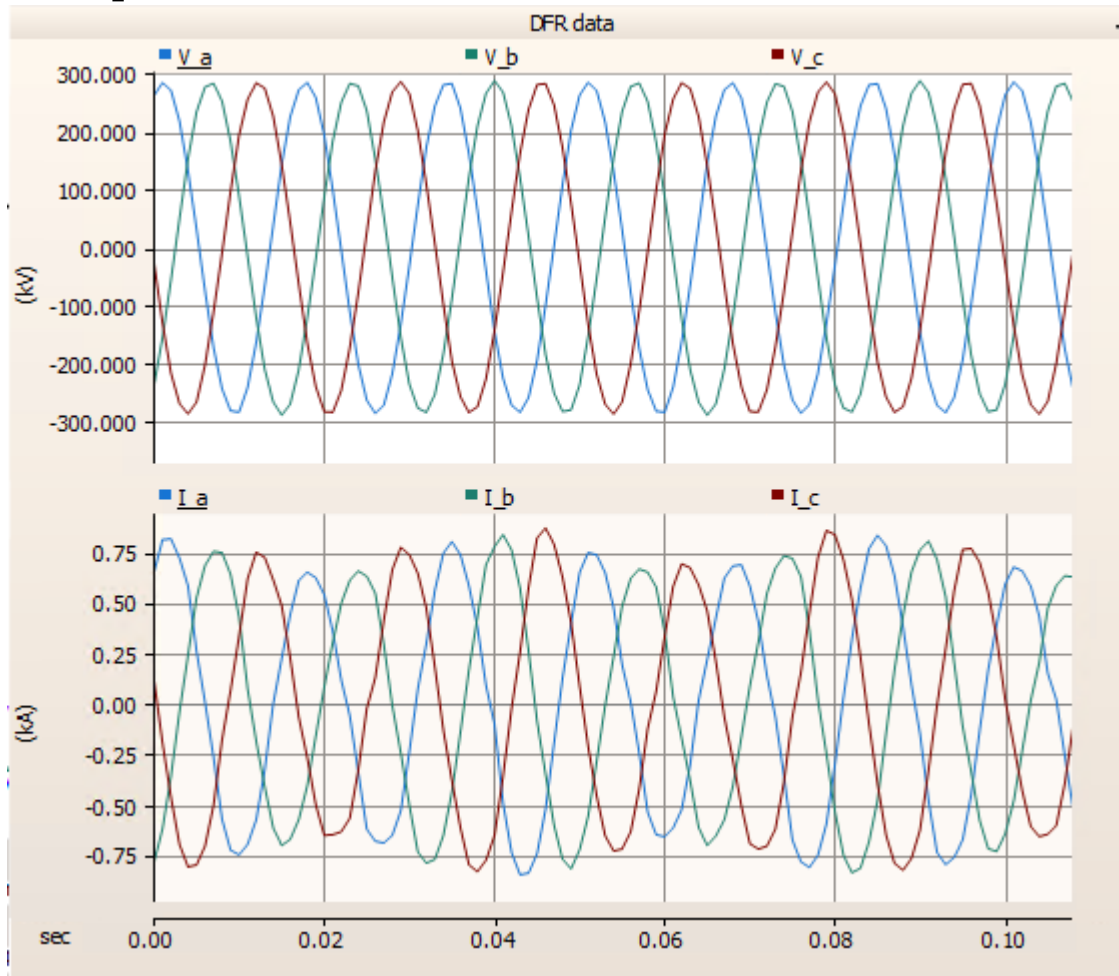
PSCAD Simulation of a Facility-Scale LEL



- **Modeling Assumptions**

- Typical parameters used where data missing
- Based on device-level model
- Transformer & collector system not provided → assumed typical
- Protection & LVRT details not available → not modeled
- Network architecture not visible → excluded

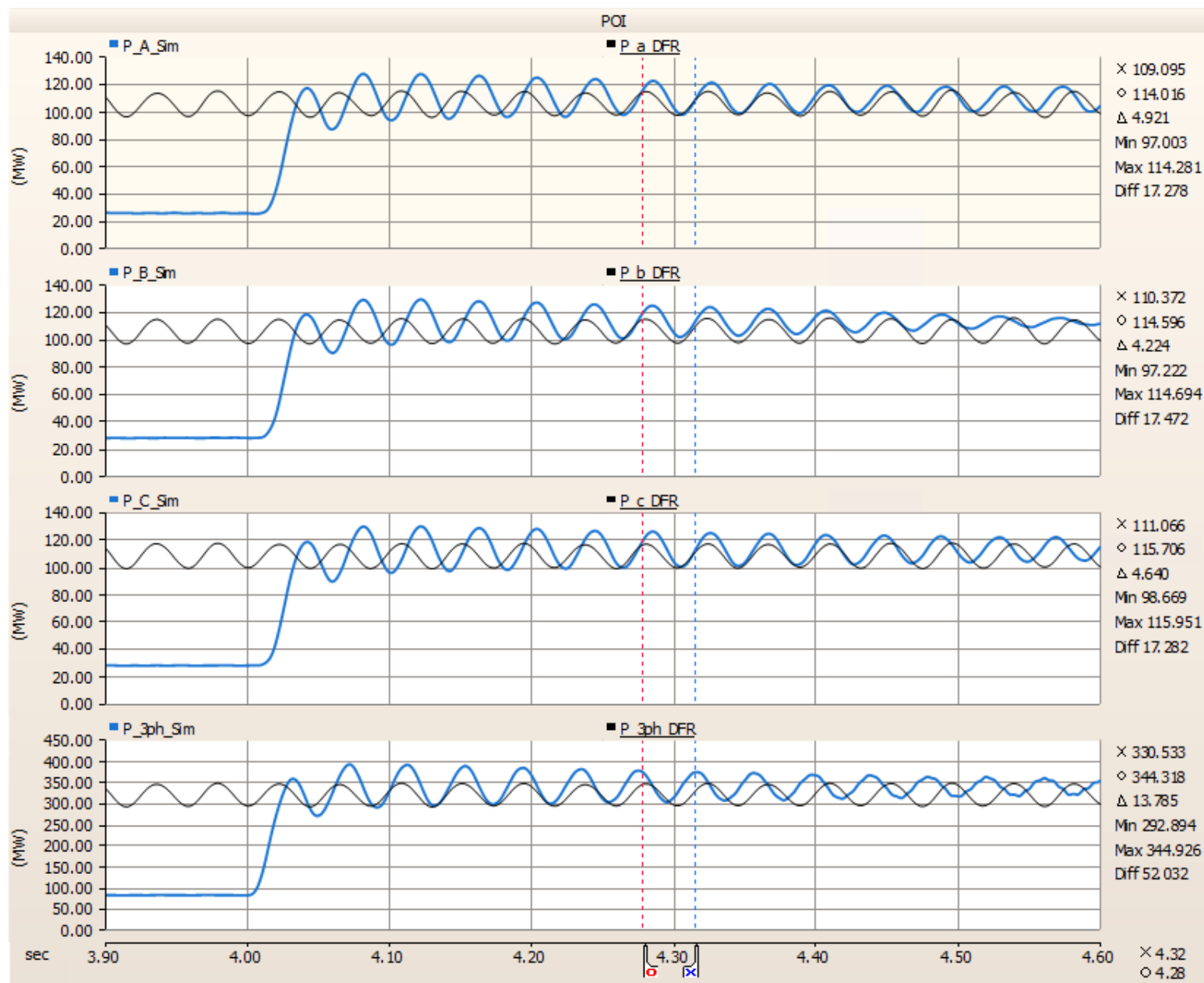
Replicate Real-World Events in Simulation



Ensure simulation reach to the desired steady state condition before introducing the event

Replicate Real-World Events in Simulation

- Active power (MW)
 - DFR data
 - **Simulation**
- Sudden power rise at 4s
- ~50 MW peak-to-peak oscillation at ~23 Hz



Speculation on the 23-Hz Oscillations

Speculation on the 23-Hz oscillations in ERCOT due to large loads

NERC Inverter-based Resource Performance Subcommittee (IRPS)

August 21st, 2025

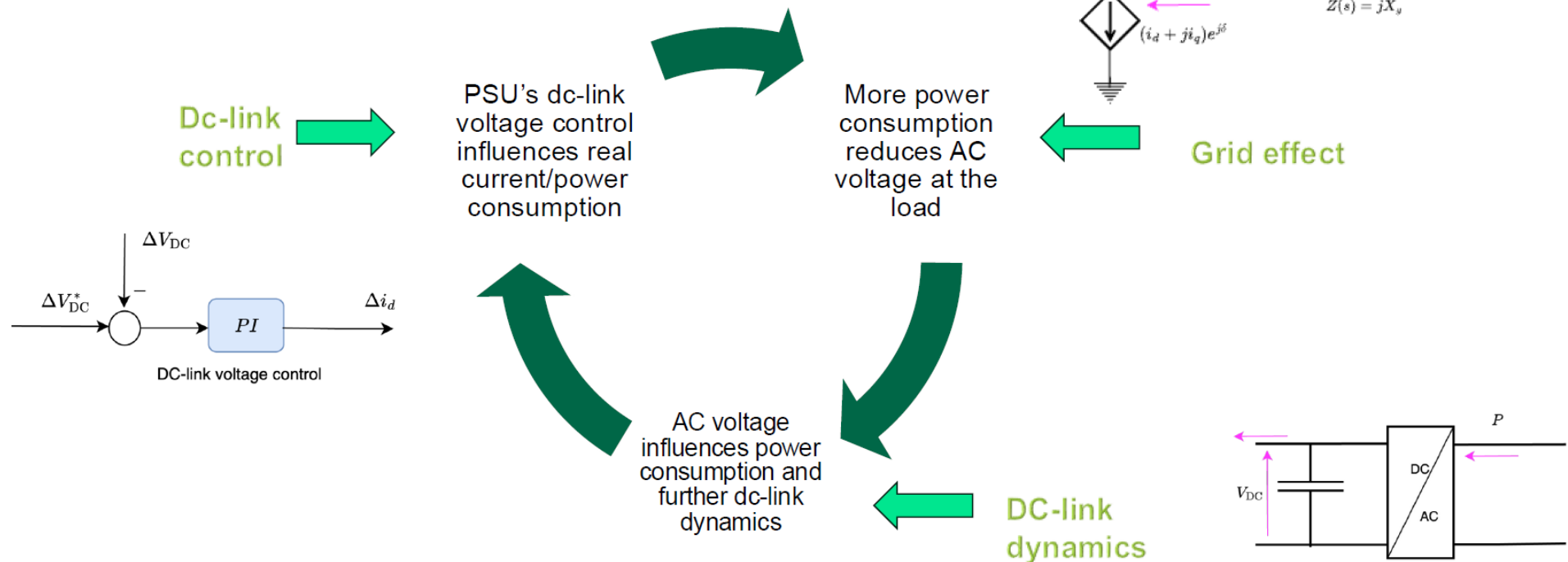
Presenter: Lingling Fan, Professor, FIEEE

Collaborators: Farshid Salehi, Yunzhi Cheng, Shahil Shah

Smart Grid Power Systems Lab
University of South Florida
<http://power.eng.usf.edu>



Analysis



Challenges Observed

- **Data Needs:** High-resolution PMU/DFR data is essential to capture oscillation magnitudes and frequency modes.
- **Standards Gap:** No industry standard currently defines required large-load performance for sub-synchronous oscillations.
- **Modeling Gap:** Existing models do not accurately represent large loads for oscillation studies.
- **Simulation Challenge:** Phasor-domain (positive-sequence) simulations cannot capture sub-synchronous oscillations.
 - EMT simulations is needed for accurate analysis

Future works

- **ERCOT EMT Modeling Priorities**
 - Crypto miners
 - UPS systems
 - Cooling systems
 - Large load architecture
- Build device-level models → scale to facility-level data center and LEL models.
- Parallel work: develop voltage ride-through curves and oscillation screening methods.