

GRID EMT

SIMULATION INITIATIVE

Large Computational Loads in ERCOT: Essential EMT Requirements and Modeling Challenges

Ali Yazdanpanah

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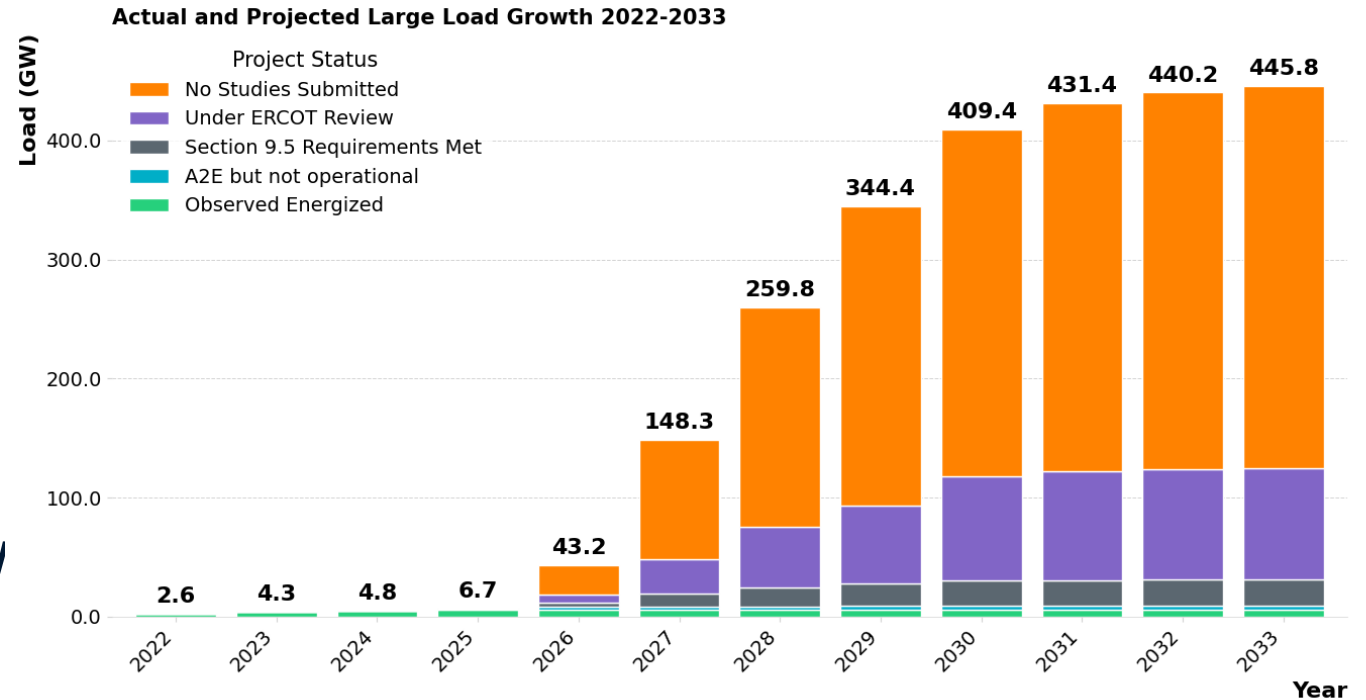


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Motivation: ERCOT Large Loads (LLs) Queue

- 445 GW of large loads seeking interconnection ~87% are data centers.
- ERCOT forecasts ~368 GW system demand by 2032.
- For comparison, the current all time peak demand is 91,089 MW on July 22, 2026.



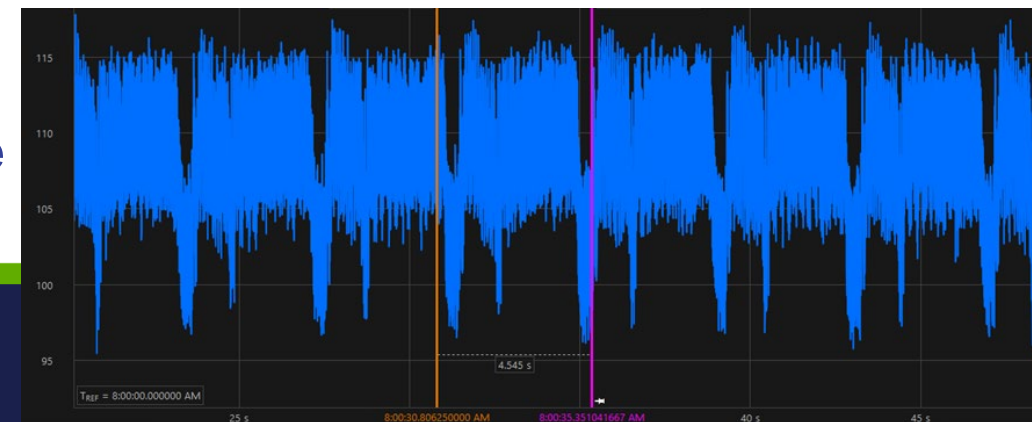
Project Status	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
No Studies Submitted	0.0	0.0	0.0	0.0	24.9	99.7	184.4	251.3	291.6	309.2	316.6	321.0
Under ERCOT Review	0.0	0.0	0.0	0.0	6.4	29.3	50.6	65.6	87.3	91.3	92.6	93.7
Section 9.5 Requirements Met	0.0	0.0	0.0	0.0	3.3	10.6	16.1	18.4	21.5	21.7	21.9	22.0
A2E but not operational	0.0	0.0	0.0	0.9	2.7	2.9	2.9	3.2	3.2	3.2	3.2	3.2
Observed Energized	2.6	4.3	4.8	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Total (GW)	2.6	4.3	4.8	6.8	43.2	148.4	259.9	344.4	409.5	431.3	440.2	445.8



Challenges Observed with LLs

- Unlike Traditional Loads, Nearly all LLs use Power-Electronics Front-Ends
- Sensitive to Voltage Sags
 - **Unbalance Partial tripping** of facilities, Maintaining proper generation-load balance is critical for frequency stability during disturbances
- Forced/Abrupt Power Demand Variations (Force Oscillation)
 - Stressing generation and transmission systems
- Weak Grid → PLL + DC-Link loops amplify disturbances

EMT simulation is the only modeling approach capable of reproducing these real-world behavior of LLs



ERCOT's EMT Model Requirement for LLs

- **Planning Guide Revision Request -144: Key Requirements for LLs**
 - Provide a PSCAD EMT model
 - Benchmark PSCAD vs. PSS/E (Model Quality Testing)
 - Demonstrate Voltage Ride Through (**Nodal Operating Guide Revision Request 282**)
 - Perform hardware benchmarking for Large Computational Loads including:
 - Crypto miners, UPS, cooling systems
- EMT model improves accuracy of the PSS/E model, positive sequence is sufficient for most studies
- EMT only needed for SSO studies near series compensated lines

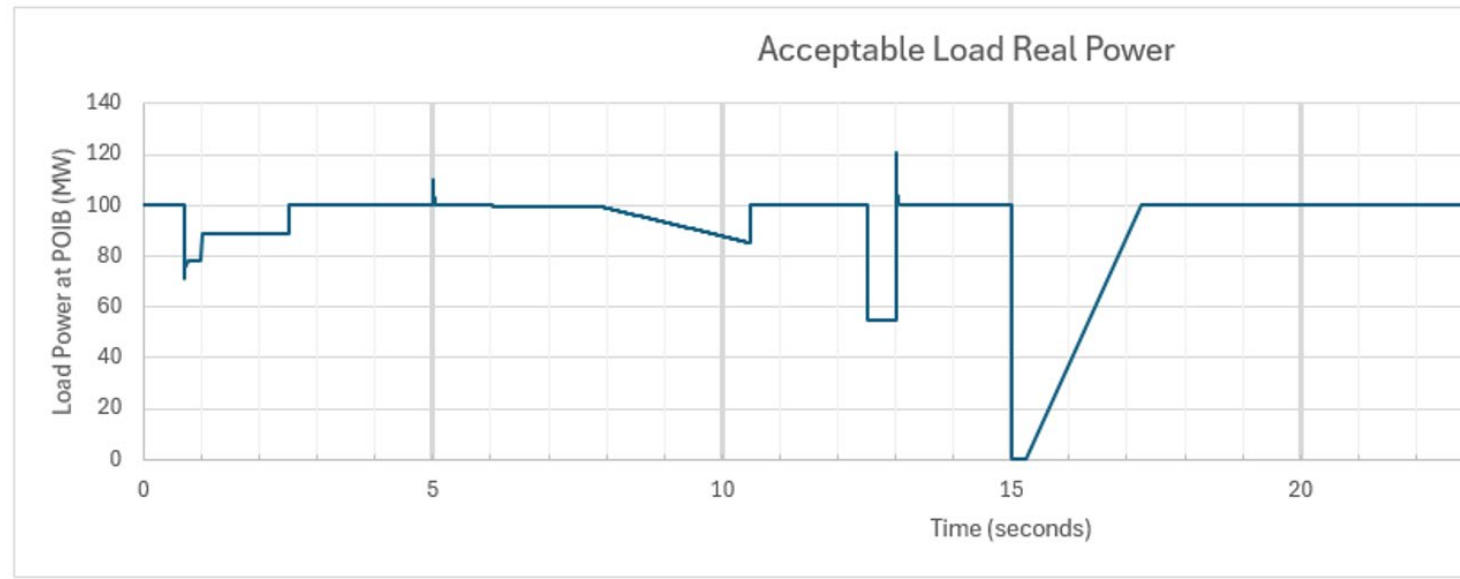
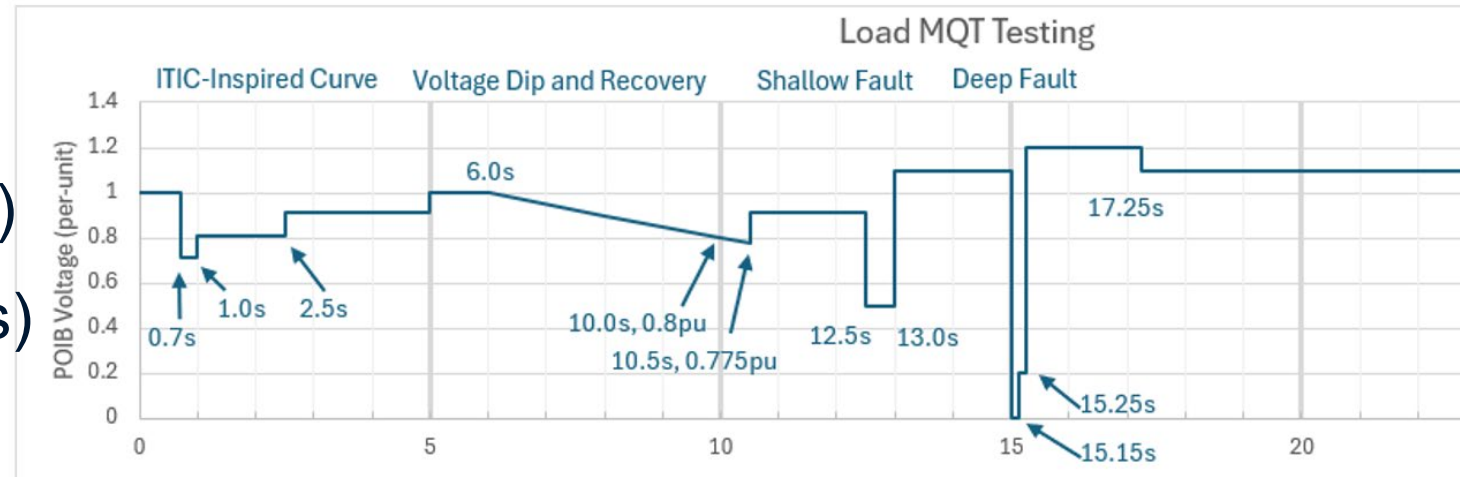


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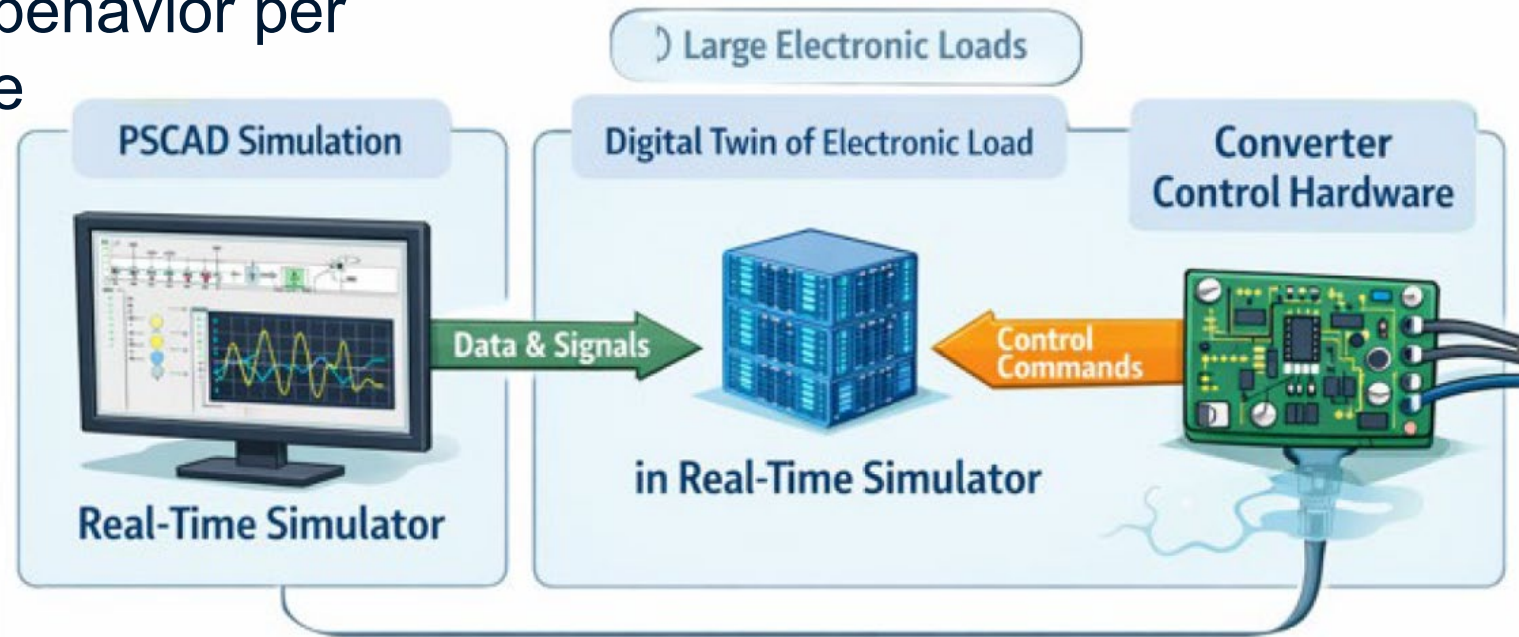
ERCOT's Voltage Ride -Through requirements per Nodal Operating Guide 282

- Normal Voltage Range (0.9–1.1 pu)
- Slight Overvoltage ($1.1\text{--}1.2\text{ pu} \leq 2\text{s}$)
- Low Voltage Range (0.5–0.9 pu)
- Post Fault Recovery Requirement
 - Once voltage at the POI rises above 0.90 pu, the LL must return to at least 90% within 2s



ERCOT's Unit Model Validation / Converter Model Validation

- Ensure PSCAD models accurately represent inverter/converter hardware behavior per section 6.2 of Planning Guide
- Tests Required for Both PSCAD Model & Hardware
 - Voltage Ride Through (VRT) Test
 - Sub-synchronous Impedance Scan (5–55 Hz)



PSCAD Model vs Hardware



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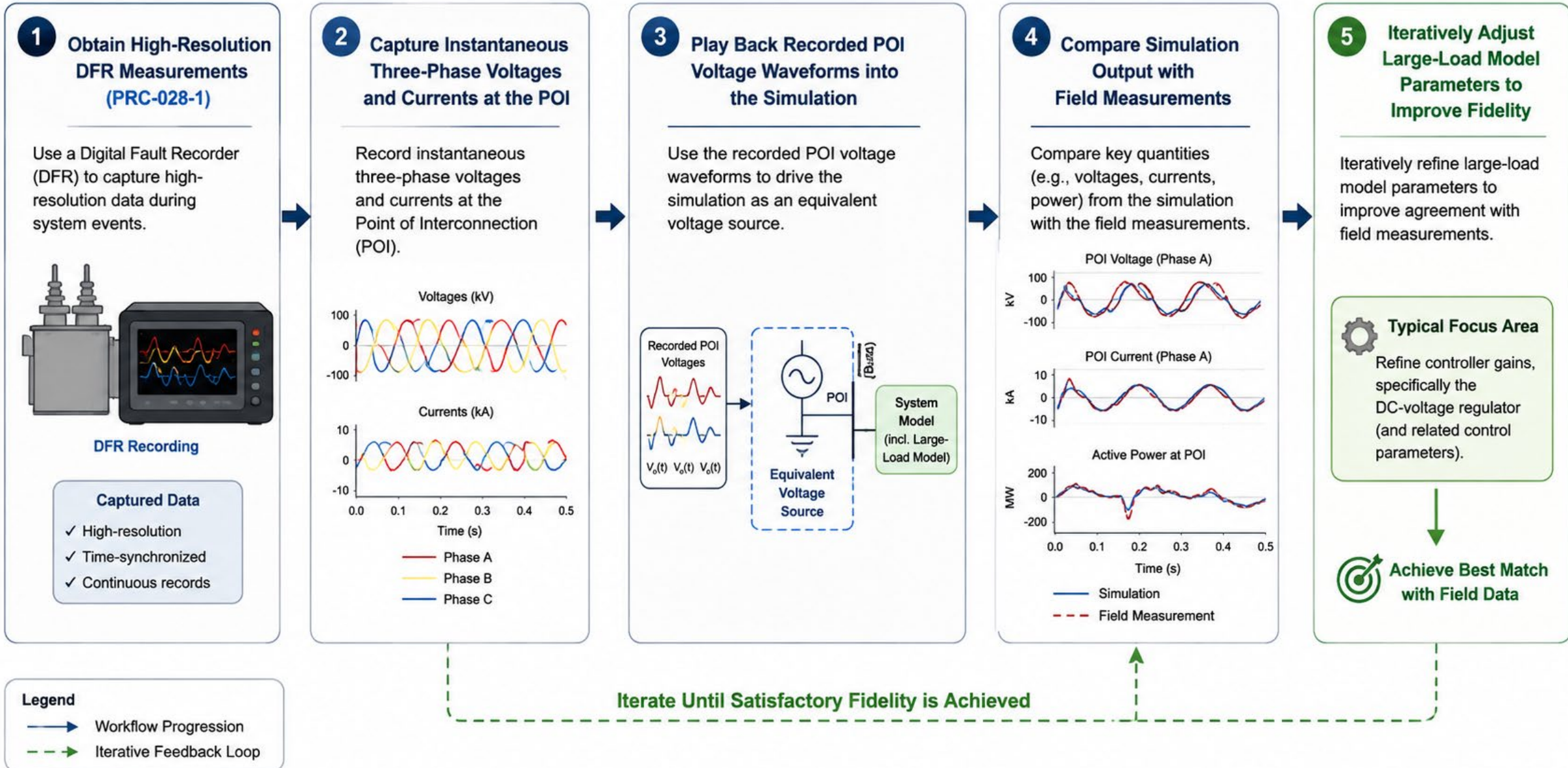
Real-World Oscillation of a Data Center in ERCOT

- Power Oscillation Summary – July 2026
 - Lower-frequency oscillations at approximately ~ 0.25 Hz with ~ 20 MW swing
 - Higher-frequency oscillations at approximately ~ 14 Hz with ~ 20 MW swing



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Replicate Real-World Events



Two Pillars of Real-World Event Replication

- **High-Fidelity EMT Model**

Represents the dynamics of the LLs, accurately. Electrical representation, Control system, protection settings, ride-through behaviors ...

- **High-Resolution DFR Data**

Provides the detailed measurements needed to reproduce and validate the observed real-world event.

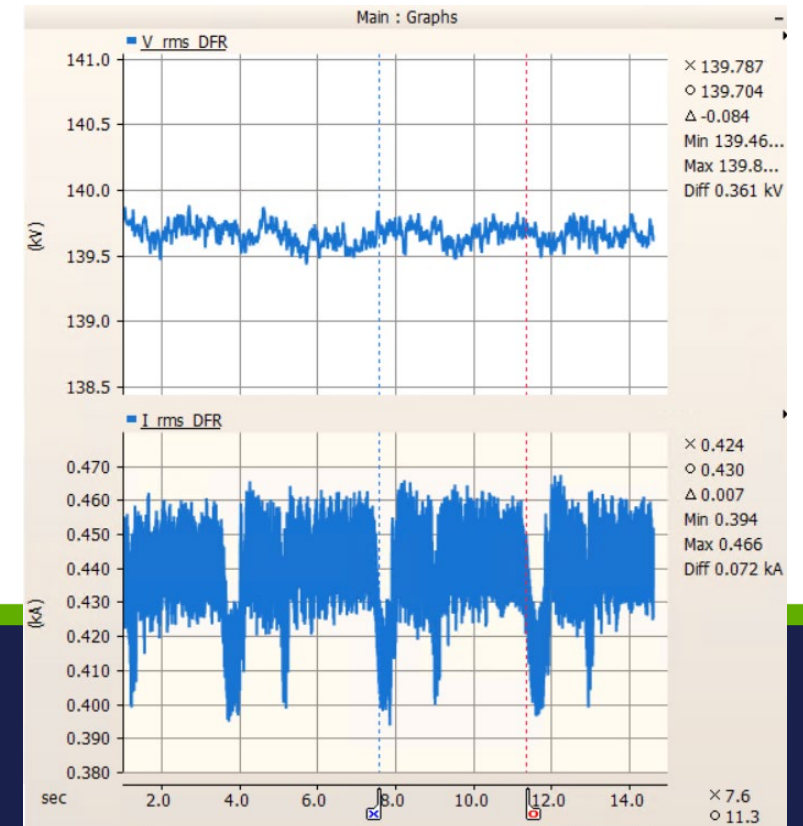
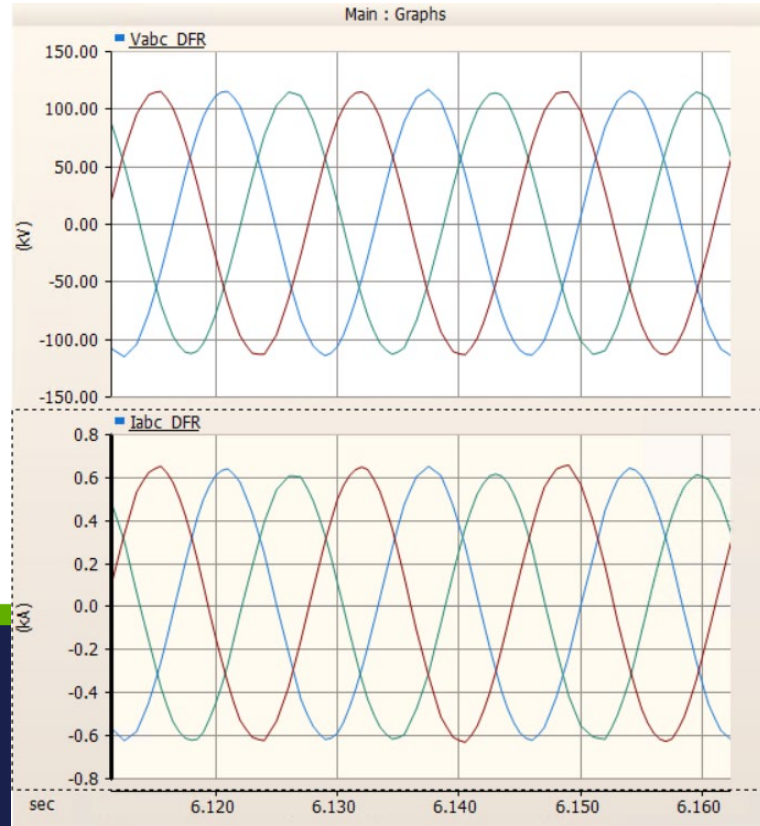
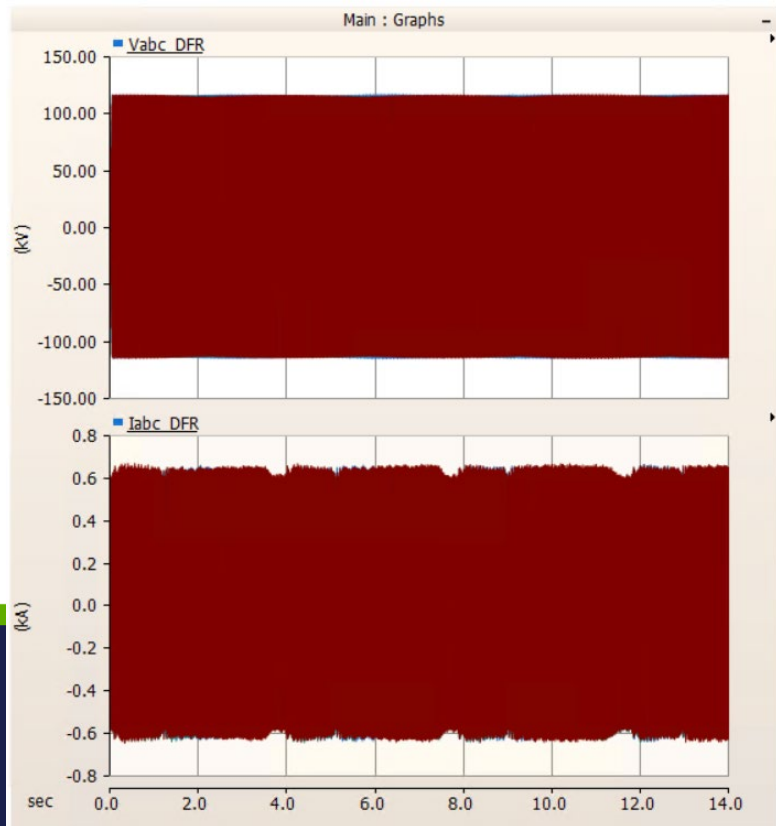
- 16 sample per cycle

! Second	B_A_PH_CURRENT	B_C_PH_CURRENT	B_B_CURRENT	
0.000000000	196.9921	96.95119	-287.6898	193.8613
0.001041667	265.7829	-21.89221	-240.764	265.7776
0.002083333	300.1784	-131.3532	-165.6984	293.9187
0.003125000	287.6709	-228.3044	-56.23979	281.4116
0.004166667	222.0069	-278.3438	59.46355	218.8757
0.005208333	140.7086	-297.1085	165.78	137.579
0.006250000	25.01486	-262.7065	240.8183	18.76077
0.007291667	-90.67888	-190.7749	284.5805	-90.6770
0.008333333	-190.7383	-90.69628	287.688	-190.7345
0.009375000	-253.2755	21.89221	234.51	-259.524
0.010416667	-284.5441	134.4807	150.0634	-287.665
0.011458333	-275.1635	234.5594	40.60416	-278.284
0.012500000	-212.6263	287.7261	-71.97308	-215.748
0.013541667	-134.4549	309.6183	-175.1635	-131.325
0.014583333	-21.88801	268.9614	-247.0734	-18.7607
0.015625000	90.67888	193.9024	-284.5813	90.67706
0.016666667	196.9921	96.95119	-290.8165	193.8613
0.017708333	262.6561	-25.01966	-240.7631	262.6508



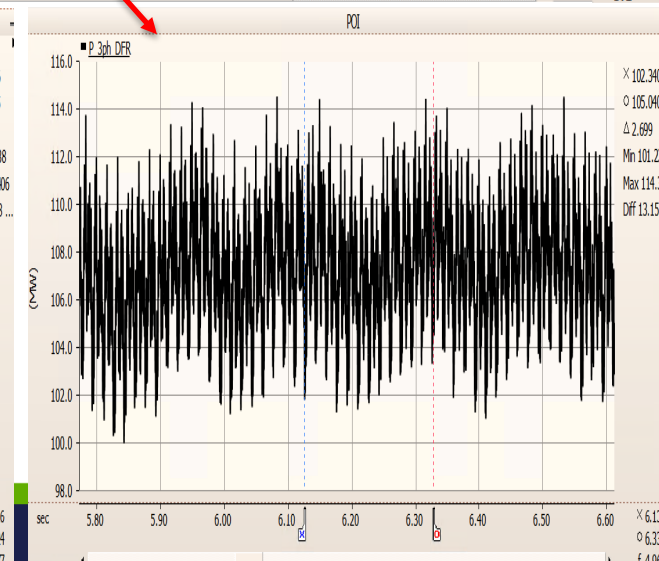
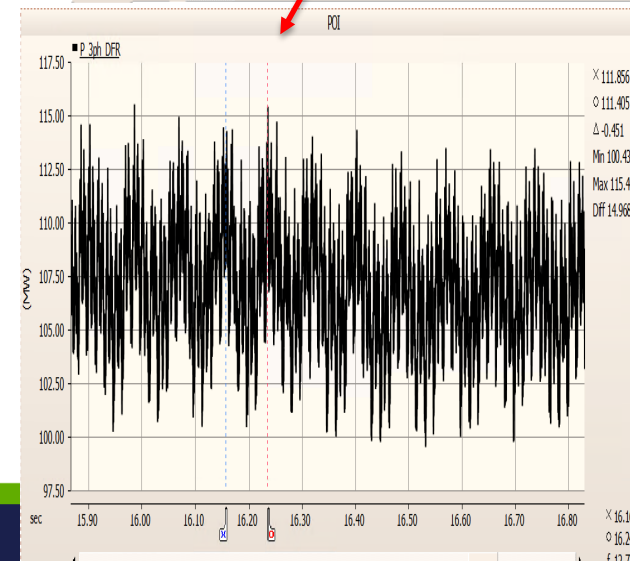
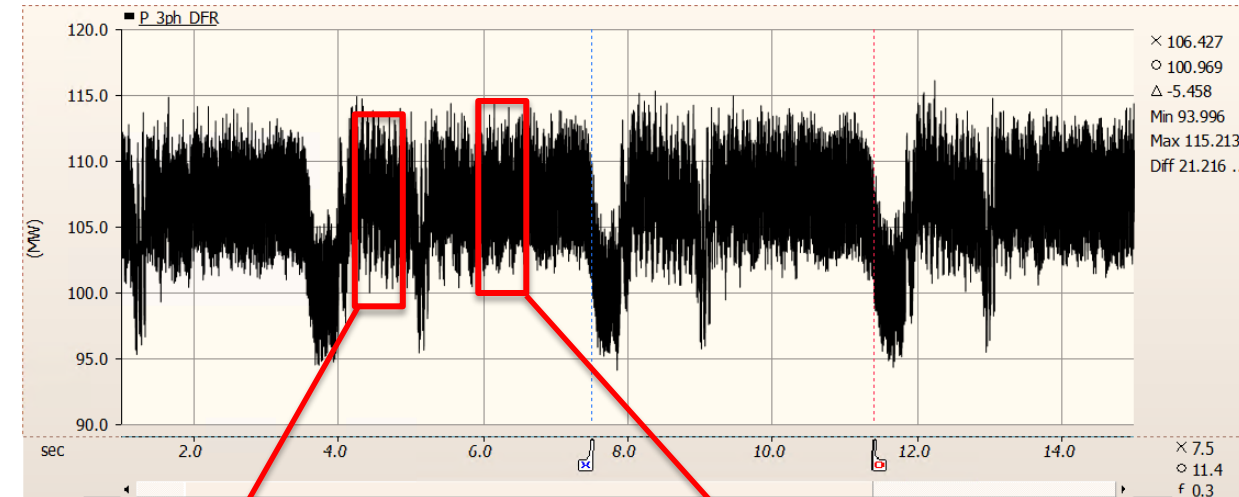
DFR Data Playback in EMT Simulation

- Instantaneous voltages and currents per phase
- RMS values for the three-phase voltage and current
- Oscillatory behavior appears clearly in RMS current, while RMS voltage remains mostly steady



Non-Periodic Oscillation Characteristics

- **Active power** was reproduced in PSCAD using DFR data.
- **Oscillation patterns** are clearly visible in the DFR power waveform.
- The signal is **not strictly periodic**, making direct frequency extraction challenging.
- **Conventional FFT analysis** alone is insufficient to reliably identify the **dominant oscillation frequency**.
- **Advanced time-frequency** or alternative signal-processing methods should be considered for improved oscillation characterization.



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Open-Source EMT Model for LLs

- ERCOT EMT Modeling Priorities

- Crypto miners
- UPS systems
- Cooling systems
- Large load architecture



Large Load Modeling

Problem: Large Electronic Load (LEL) behaves differently than conventional loads and is large enough to impact grid stability.

Solution: Develop deeper understanding of how crypto miners, datacenters, and electrolyzers work and how to model them for grid stability studies.

- Model Development Strategy

- Build device-level models
- Build facility-level LL models such as data centers.
- Develop voltage ride-through curves
- Available at: <https://www.ercot.com/about/grit/large-load-modeling>



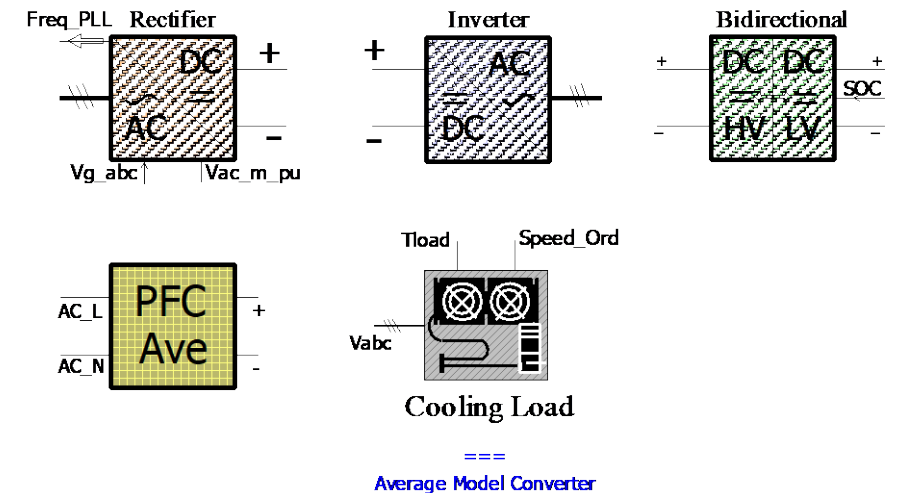
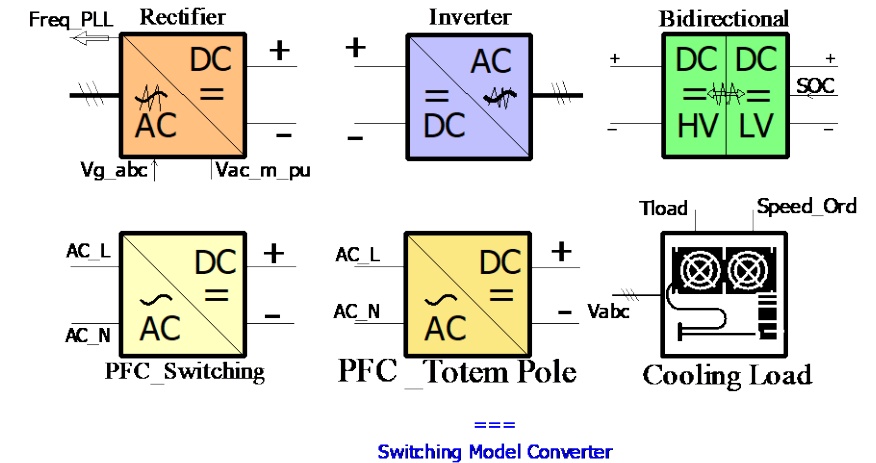
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Open-Source EMT Model Library

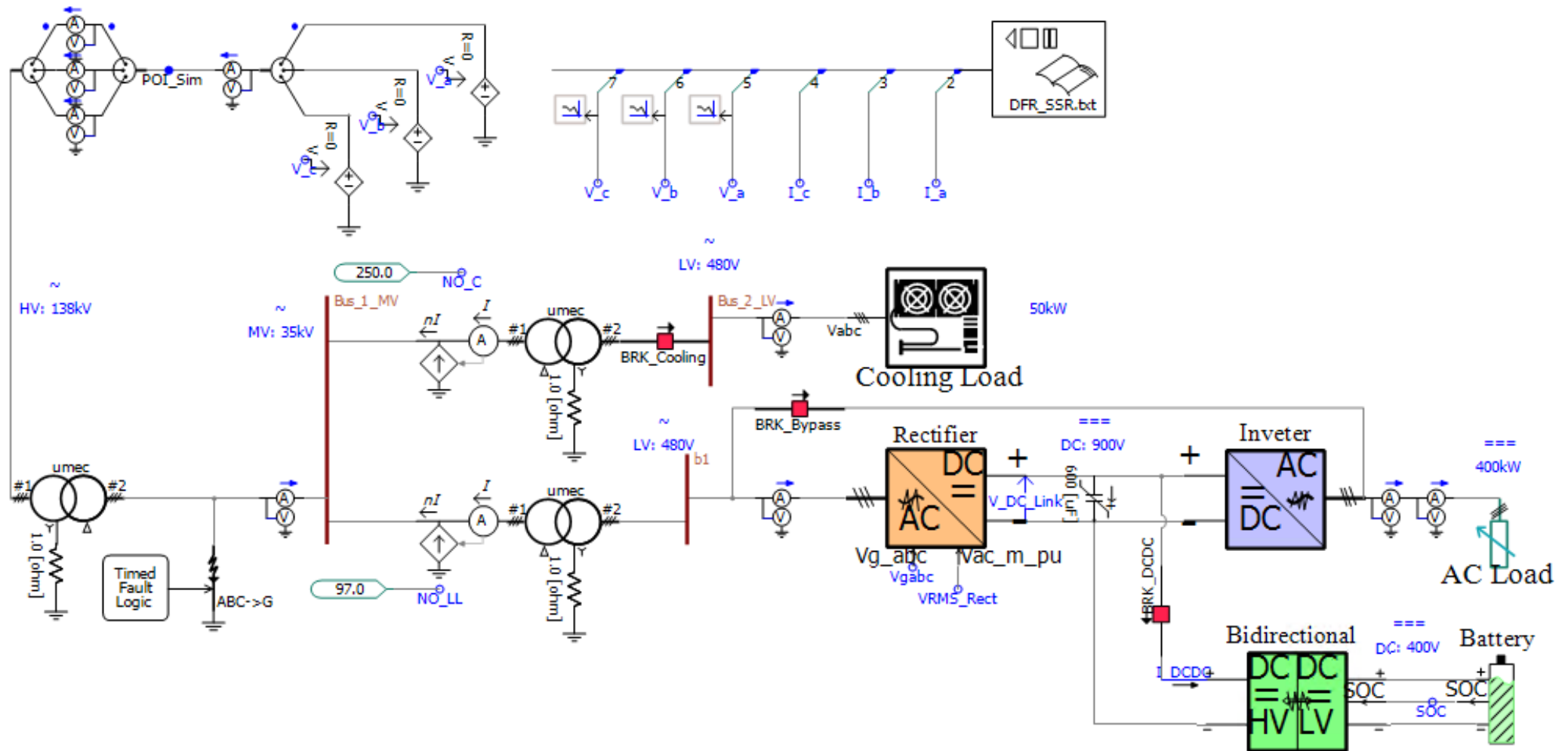
- Library Overview

- Commonly used LL components:
 - Rectifiers, inverters, DC-DC converters...
 - Provides both switching and average models.
 - These components are Modular, per-unitized, and scalable
- Switching Models
 - Capture high frequency transients - fast transient analysis.
- Average Models
 - Large-scale system behavior.
 - Reduce simulation time, while preserving essential dynamics.



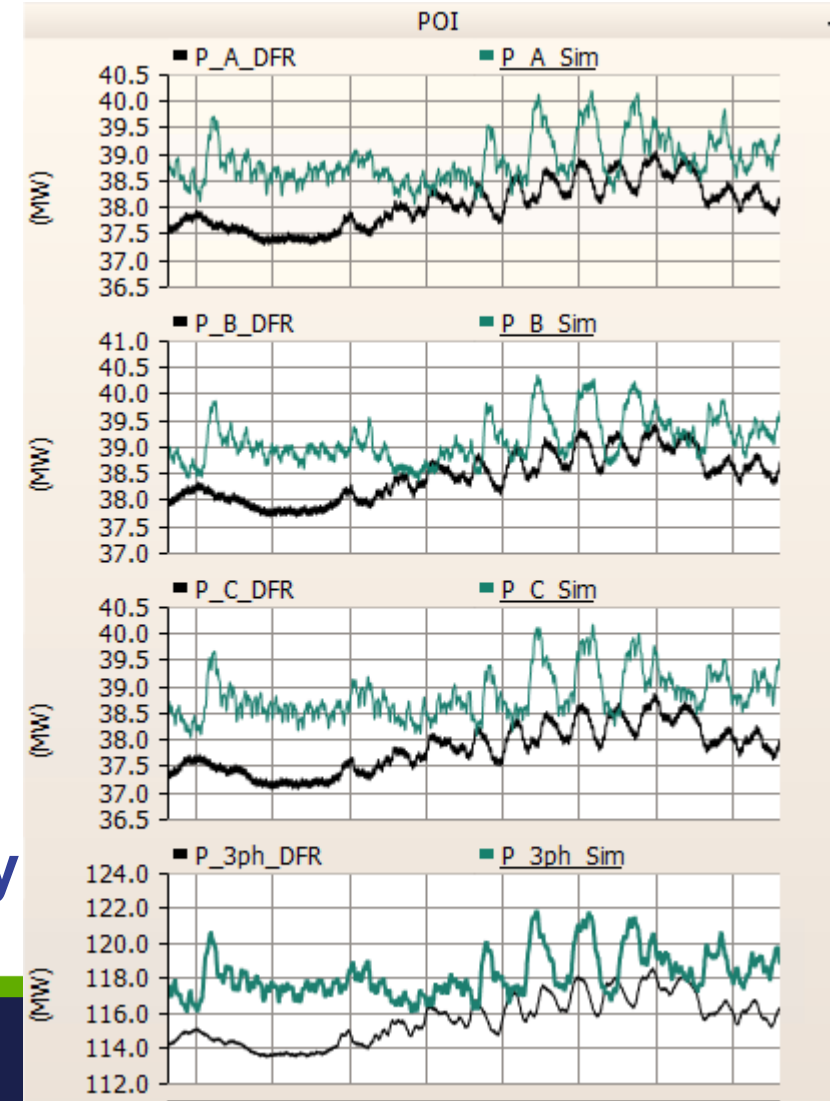
Open-Source EMT Model for Large-Scale Data Centers

- Double-Conversion UPS-Based Data Center
- Available at: <https://www.ercot.com/about/grit/large-load-modeling>



Key Factors Contributing to Oscillations

- Event Occurrence: The event occurred in July 2026.
- Modeling Assumptions: Common assumptions were made regarding the collector system, including transformer winding parameters.
- Parameters Contributing to Oscillation:
 - DC-Link Controller
 - PLL and Filter Settings
- **Importance of Data Quality: Accurate assessment of the event depends on high-quality DFR data.**



Conclusions/Next Steps

- **Rapid large-load growth:** ERCOT queue ≈ 445 GW ($\sim 87\%$ data centers); forecast ≈ 368 GW by 2032
- **Field measurements:** EMT simulation is needed to accurately capture large-load dynamic behavior
- **PGRR-144 & NOGRR-282:** Establish expectations for:
 - PSCAD EMT models
 - PSCAD-PSS®E benchmarking
 - VRT compliance
 - Hardware benchmarking of LL components
- **July 2026 oscillations:** Observed ≈ 0.25 Hz / 20 MW and ≈ 14 Hz / 20 MW, highlighting the need for high fidelity EMT models and high-resolution field measurements
- **ERCOT open-source EMT library:** Device- and facility-level models that are modular, per-unitized, and scalable, providing a foundation for SSO and other EMT studies



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