Large Electronic Load Sub-Synchronous Oscillation (LEL-SSO) Power Variation Challenges and Discussion

This is an update to the October 2025 LLWG presentation.

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Recap

- AI training processes can exhibit rapid changes in active power, impacting synchronous machines operations
- ERCOT, with Electranix's support, is developing a framework to assess and quantify the impact
- ERCOT is monitoring industry best practices and requirements, and will collaborate with stakeholders to establish necessary requirements and processes to mitigate risks

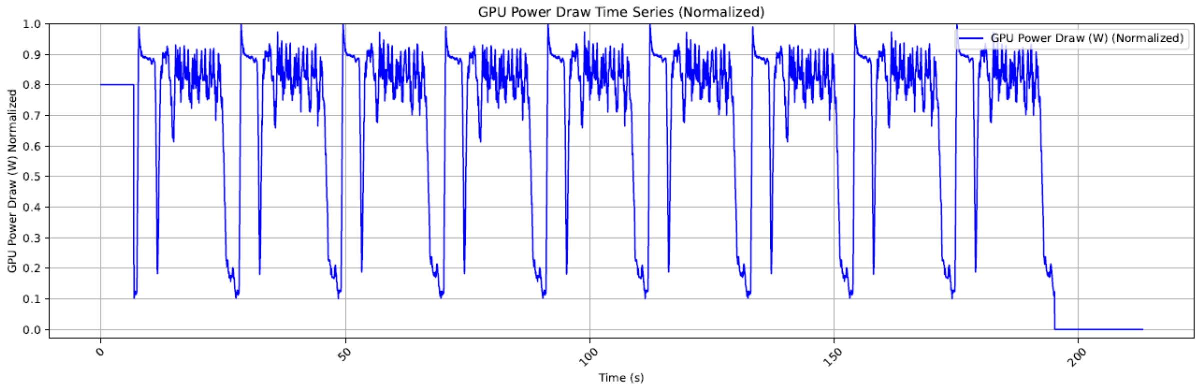


Fig. 1. Power readings from an at-scale training job on DGX-H100 racks.

Power Stabilization for AI Training Datacenters

Esha Choukse, Brijesh Warrier, Scot Heath, Luz Belmont, April Zhao, Hassan Ali Khan, Brian Harry[1], Matthew Kappel, Russell J. Hewett[1], Kushal Datta, Yu Pei, Caroline Lichtenberger, John Siegler, David Lukofsky[1], Zaid Kahn[1], Gurpreet Sahota, Andy Sullivan, Charles Frederick, Hien Thai, Rebecca Naughton[1], Daniel Jurnove, Justin Harp[1], Reid Carper, Nithish Mahalingam, Srini Varkala, Alok Gautam Kumbhare, Satyajit Desai, Venkatesh Ramamurthy, Praneeth Gottumukkala, Girish Bhatia, Kelsey Wildstone, Laurentiu Olariu, Ileana Incorvaia, Alex Wetmore, Prabhat Ram, Melur Raghuraman, Mohammed Ayna, Mike Kendrick, Ricardo Bianchini
Microsoft

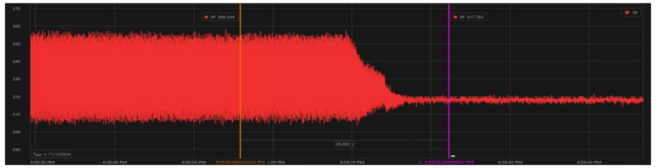
Aaron Hurst, Reza Zamani, Xin Li, Michael Petrov, Gene Oden, Rory Carmichael
OpenAI

Tom Li, Apoorv Gupta, Pratikkumar Patel, Nilesh Dattani, Lawrence Marwong, Rob Nertney, Hirofumi Kobayashi, Jeff Liott, Miro Enev, Divya Ramakrishnan, Ian Buck, Jonah Alben
NVIDIA

Has this occurred in the field? Yes (July 2025 LLWG Recap)

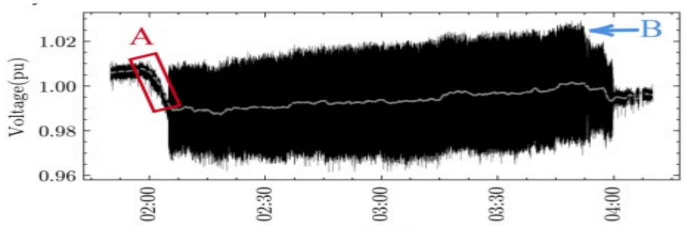
- ERCOT 23 Hz Event (July-October 2024)

https://www.ercot.com/files/docs/2025/02/28/LL-Oscillation_LFLTF_Mar2025_Final.pptx



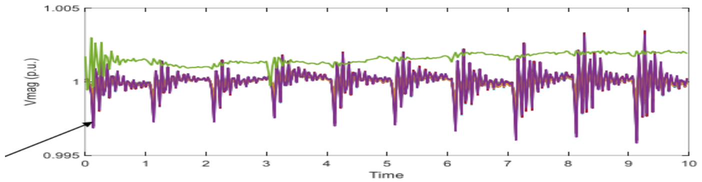
- Dominion Energy 14.7-14.8 Hz Event

https://www.researchgate.net/publication/389098360_Understanding_the_Inception_of_147_Hz_Oscillations_Emerging_from_a_Data_Center

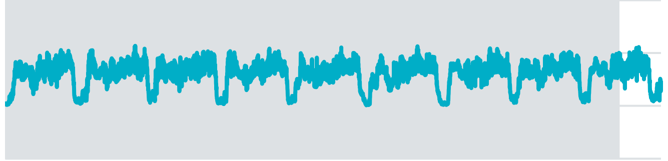


- Dominion Energy 1-11 Hz Event

https://www.epri.com/events/539b60d7-57da-4252-9968-fb1754ee3b66



- ERCOT LEL normal load profile (Dec. 2025)



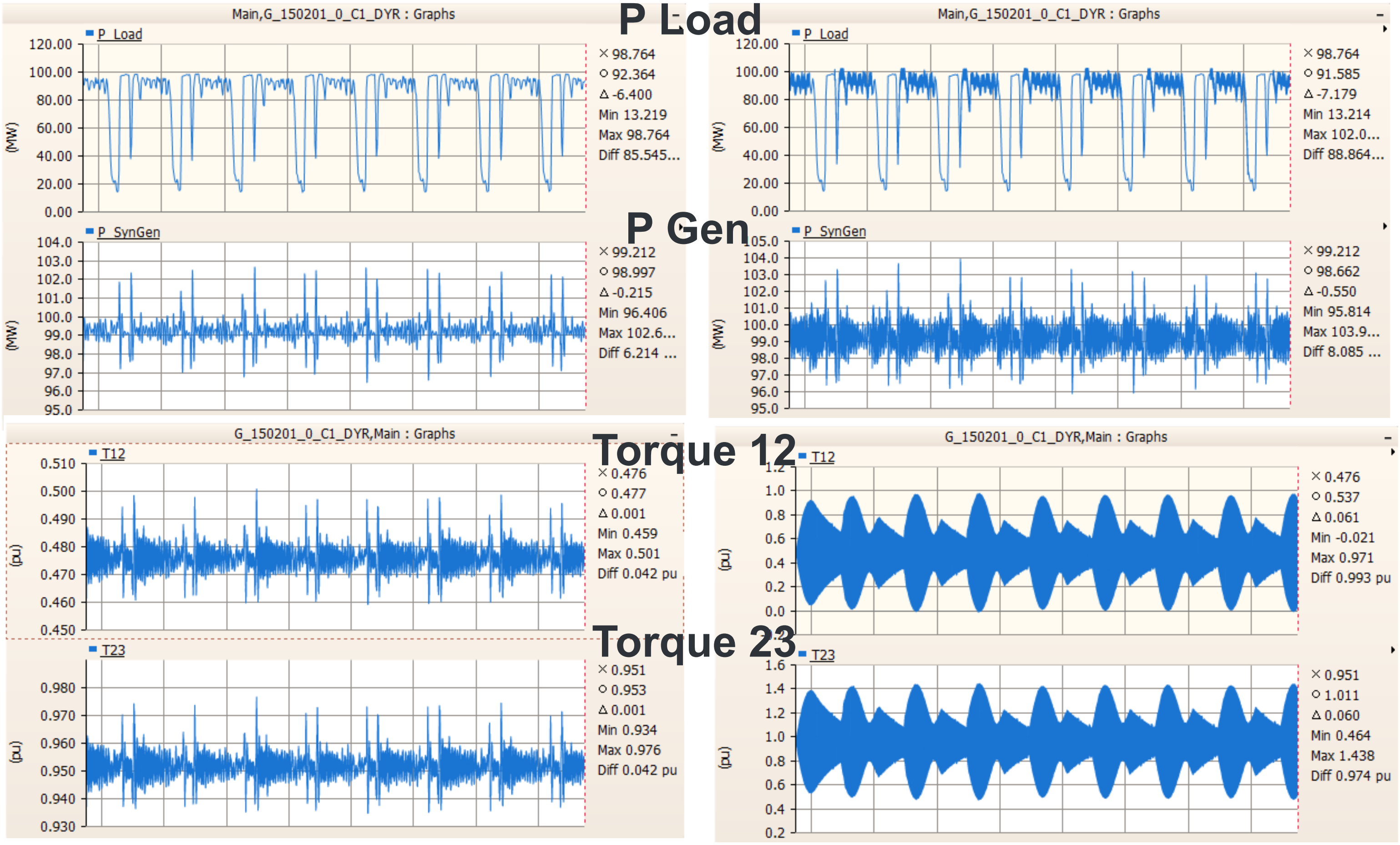
LEL load profiles may lead to continuous torque perturbations on synchronous generator shafts, potentially causing damage or fatigue to the generator equipment

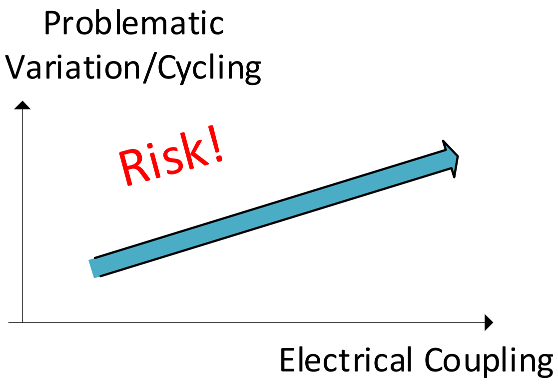
Example: synchronous generators (1970 Mohave event)

Selected Simulation Results and Considerations

Load profile 2 – Scenario S9 (similar to paper on slide 2)

Load profile 2 with 12 Hz – Scenario S13 (similar to paper on slide 2)





- Large load power variation propagates to generators and creates oscillatory shaft torque
- Frequency overlap with torsional modes can cause strong torque amplification
- Cyclic loads and electrically close generators pose the highest risk
- Sustained excitation may lead to shaft fatigue or damage
- OEM and owner input is essential to define limit, capability and mitigation

Technical Assessment Framework Development

- **Step 1: Determine the maximum continuous terminal variation (MCTV) in active power for synchronous generators** (mechanical limit → electrical limit)
  - **Endurance Limit (EL):**
    Maximum continuous cyclic shaft torque a synchronous generator can withstand without fatigue or damage
  - **Load Shape Ratio (LSR):**
    Amplification factor between terminal active-power variation and internal shaft torque
    Depends on:
    - Degree of overlap with torsional modes
    - Persistence of the torsional frequency content
  - **Maximum Continuous Terminal Variation (MCTV):**
    The maximum amount of continuous active power variation at the SG terminals without exceeding the given mechanical endurance capability. MCTV = LE / LSR
- **Example:**
  If EL = 0.1 pu and LSR = 10 → MCTV = 0.01 pu
  For a 100 MW generator → allowable continuous oscillatory power at SG terminal is 1 MW

Technical Assessment Framework Development

- **<u>Step 2: Calculate the maximum allowable power variation at LEL terminal</u>**
  - Use a load-flow or impedance-based approach to calculate the Interaction Factor–Based Limit (IFBL)
    - maximum LEL power variation such that no nearby generator exceeds its MCTV
  - The most limiting generator sets the IFBL for that load location

- **Example:**
  - If a LEL operates at its IFBL, nearby generators remain within safe torque limits
  - Any additional LEL connected at the same location must maintain minimal or flat power variation, as the first LEL already consumes the allowable variation margin

- The technical framework has been developed to apply Step 1 and Step 2 across the entire ERCOT grid, allowing us to quantify the maximum permissible active power variation at each LEL such that no torsional torque violation at nearby generators.

First, an analogy…

- Imagine we're managing a public library that welcomes everyone (generators and loads)
- General desire to keep library quiet for readers, at least in a way not to affect others.

The Challenges

- We have developed the framework to quantify the noise level, but w*hat noise level (power variation) is unacceptable for the people in the library (existing generators) and others plan (new generators) to come to the library?*

- The challenges:
  1. Large Load variations are not well defined and can change with software.
  2. Generator owners are unable to articulate exactly what torque variation (noise level) is unacceptable.
  3. Have a relaxed requirement (allow higher noise level) may annoy some people in the library and prevent people (increase complexity and difficulty of new gen/load to come to the library
  4. Have a restricted requirement (keep low noise level) may require more behaved people and checking but allow more people

Framework Options

Option 1: Individualized Requirements: Project-specific power variation limits based on detailed studies.	Option 2: Tiered / Hybrid Requirement: Baseline power variation limit applies to all LELs, with additional screening to identify higher-risk projects that require stricter limits.	Option 3: System-Wide Requirements: Uniform power variation limits applied to all large loads without project-specific studies.
- Maximizes load flexibility - Address specific SSTI risk on local system conditions	- Balances simplicity and risk-targeting - Reduces overall study burden vs. fully case-by-case - More adaptable to future grid changes	- Transparent and consistent requirement for project to implement - No individual EMT studies required - Accommodates future transmission and generation changes
- Heavy EMT study burden - Extends interconnection timelines - Requires re-studies as load behavior changes - Ongoing compliance monitoring and higher operational complexity - Provides little margin for future nearby synchronous generators	- Screening can be complex to implement - Detailed studies still needed for some projects - Re-evaluation may be required if grid or load changes - Potential to miss issues depending on screening approach - Risk of limited margin over time	- Require extensive coordination and detailed system assessment - Incorrect limits could either miss risks or over-constrain loads.

Next Steps

- ERCOT is working with the industry to identify ways to manage the LEL-SSO problem due to LEL's fast active power variation and its impact to the synchronous generators which cause the machine life and stable operations
- Considerations:
  - A very strict "no oscillation / slow ramping" load requirement would result in the least number of studies and not restrict where future loads or generators can locate. However, the feasibility and impact to the large loads should be considered.
  - A more relaxed oscillation requirement would require more studies. These studies are far more difficult than traditional SSO studies, because the load profiles are not well defined (may change) and generator tolerance for repetitive disturbances is not well understood and difficult to quantify.
    - Studies may quickly become impractical in areas with lots of loads / generators
    - Essentially, our library (grid) may need a "*whisper voices only*" blanket policy
- Have the draft process and requirements by Q1 2026

Thank you!