EMT Testing of Large Load Power Fluctuation Mitigation

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Background: Large Load Characteristics

- AI training processes can exhibit fast variation in active power.
- Data center loads are not designed to ride through system events (UPS doesn't count)
- Loads are a mix of types of converter-based interfaces
- Reliability risk
  - Synchronous generator damage
  - Flicker
  - Machine mode oscillations
  - Interarea oscillations

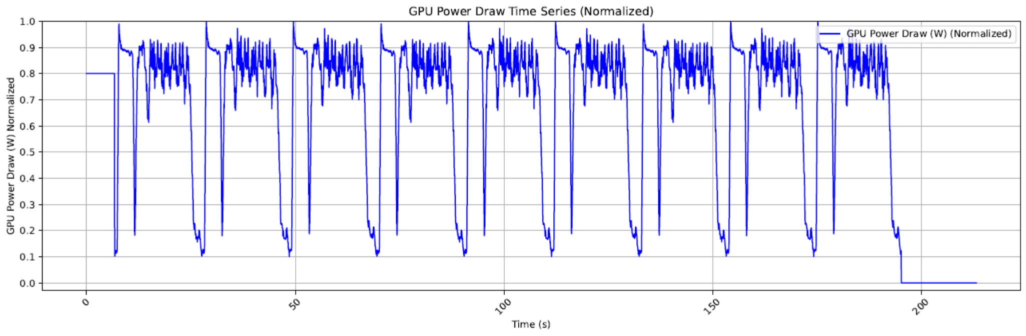


Fig. 1. Power readings from an at-scale training job on DGX-H100 racks.

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

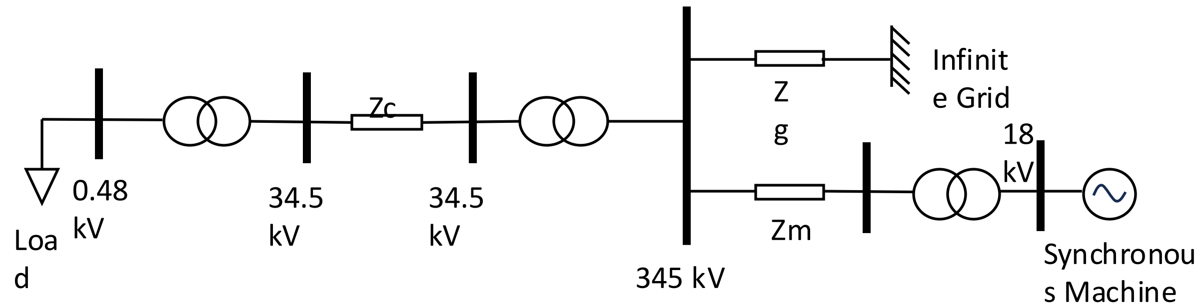
Aaron Hurst, Reza Zamani, Xin Li, Michael Petrov, Gene Oden, Rory Carmichael

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

Example (ERCOT study)



Key Parameters:

- Machine Rating = 100 MW
- **Synchronous machine key torsional mode: 12 Hz**
- Load profiles:
  - Profile 1 (S1 – S8): Fixed frequency square wave varying between 25 MW and 100 MW with a ramp rate of 10 MW/1ms
  - Profile 2 (S9 – S16): Proxy waveform mimicking measured AI training load profile

Scenario No.	Load Variation	Max Pk-Pk Active Power Variation* (Generator electrically close: Zm = 0)			Alternating Torque	
		At the Load	At the Machine	At the Grid	Tau12 (pu)	Tau23 (pu)
	Hz	MW	MW	MW		
S1	Load profile 1 at 2 Hz	76.81	32.98	77.81	0.233	0.234
S5	Load profile 1 at 12 Hz	77.61	11.89	82.55	5.124	5.028
S9	Load profile 2	85.55	6.21	87.44	0.042	0.042
S13	Load profile 2 with 12 Hz oscillations	88.86	8.09	92.22	0.993	0.974

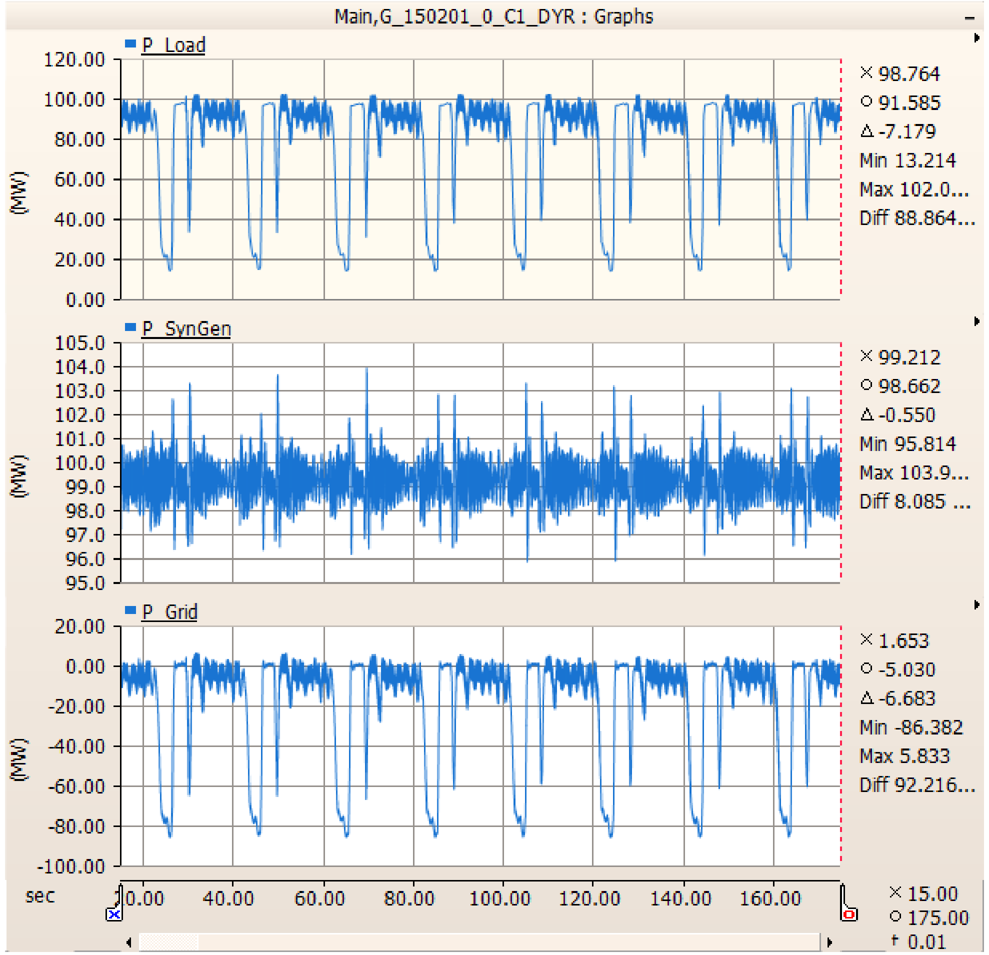
**Note: Split of active power between machine and grid is initially determined by impedance split, and the final variation will depend on the frequency of the variation and other machine characteristics over time. Ref. ERCOT LLWG October 24 meeting:*

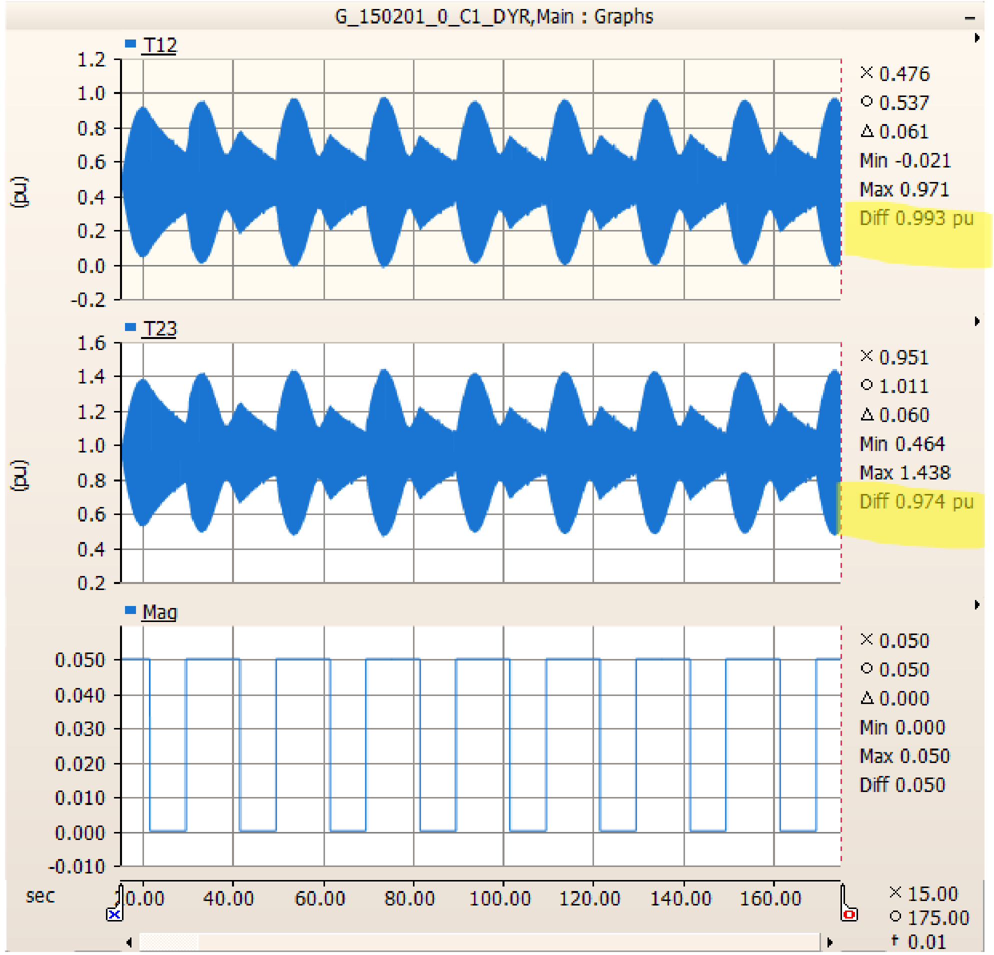
Results: Load profile 2 with 12 Hz – S13 (similar to paper on slide 2) **1pu Torque**

P Load

P Gen

P Grid





Torque 12

Torque 23

Per unit 12 Hz Component

Key EMT modeling aspects of mitigation studies

- Power variation grid criterion is required to mitigate against.
- Supplementary device(s) with **energy storage** is required.
- Load profiles, including load shapes and ramp rates, must be carefully selected.
- Real-code models of power supply unit (PSU) and/or UPS systems should be included or load profiles should be adjusted accordingly.
- System strength at the point of connection is important for the efficiency of GFM compensation (if utilized).
- A relatively small EMT model will be sufficient

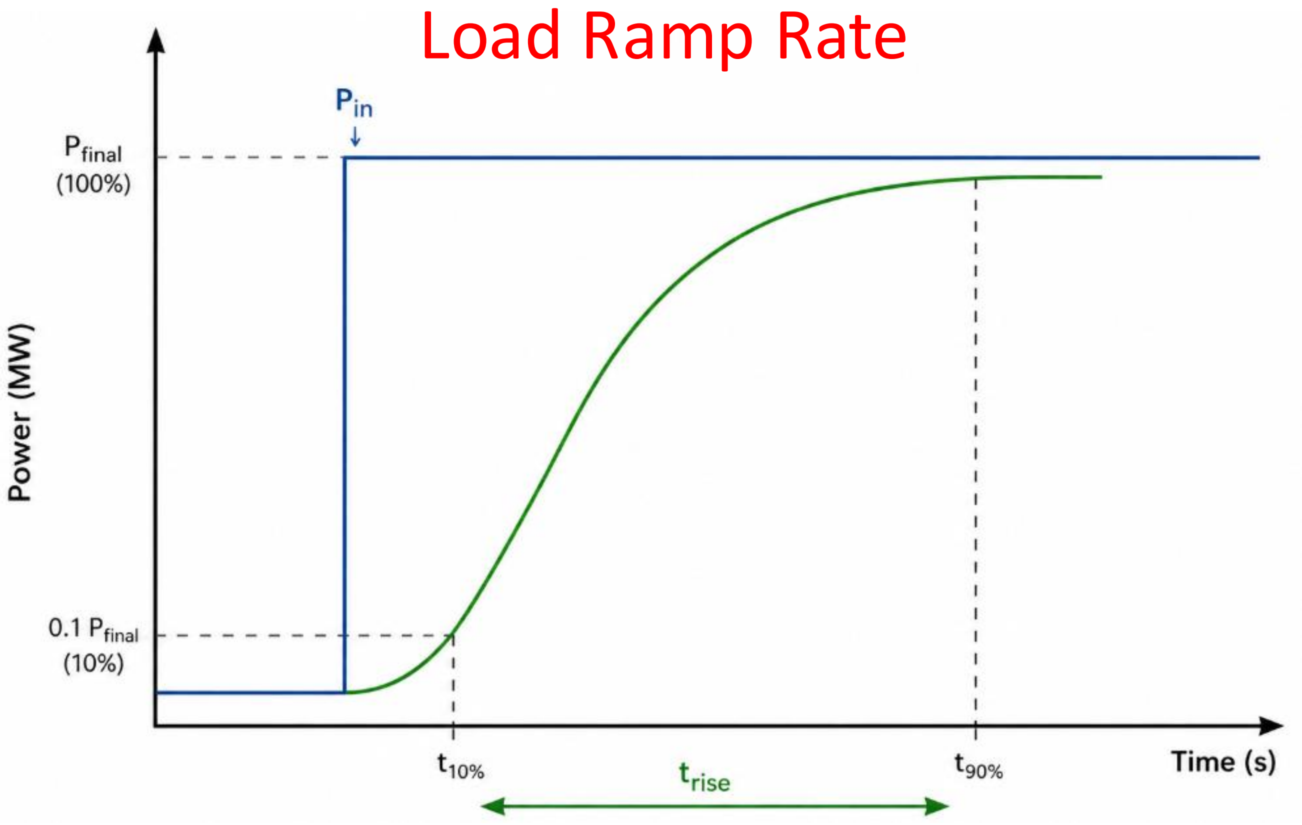
Mitigation Options (this is growing)

1. GFM BESS
2. BESS with active load compensation functionality
3. E-STATCOM
4. E-STATCOM + GFM BESS
5. Double Conversion UPS (Low Voltage)
6. Double Conversion UPS (Low Voltage) + GFM BESS
7. Double Conversion UPS (Medium Voltage)
8. GPU Level Mitigation

Critical factors in EMT modelling of mitigation devices

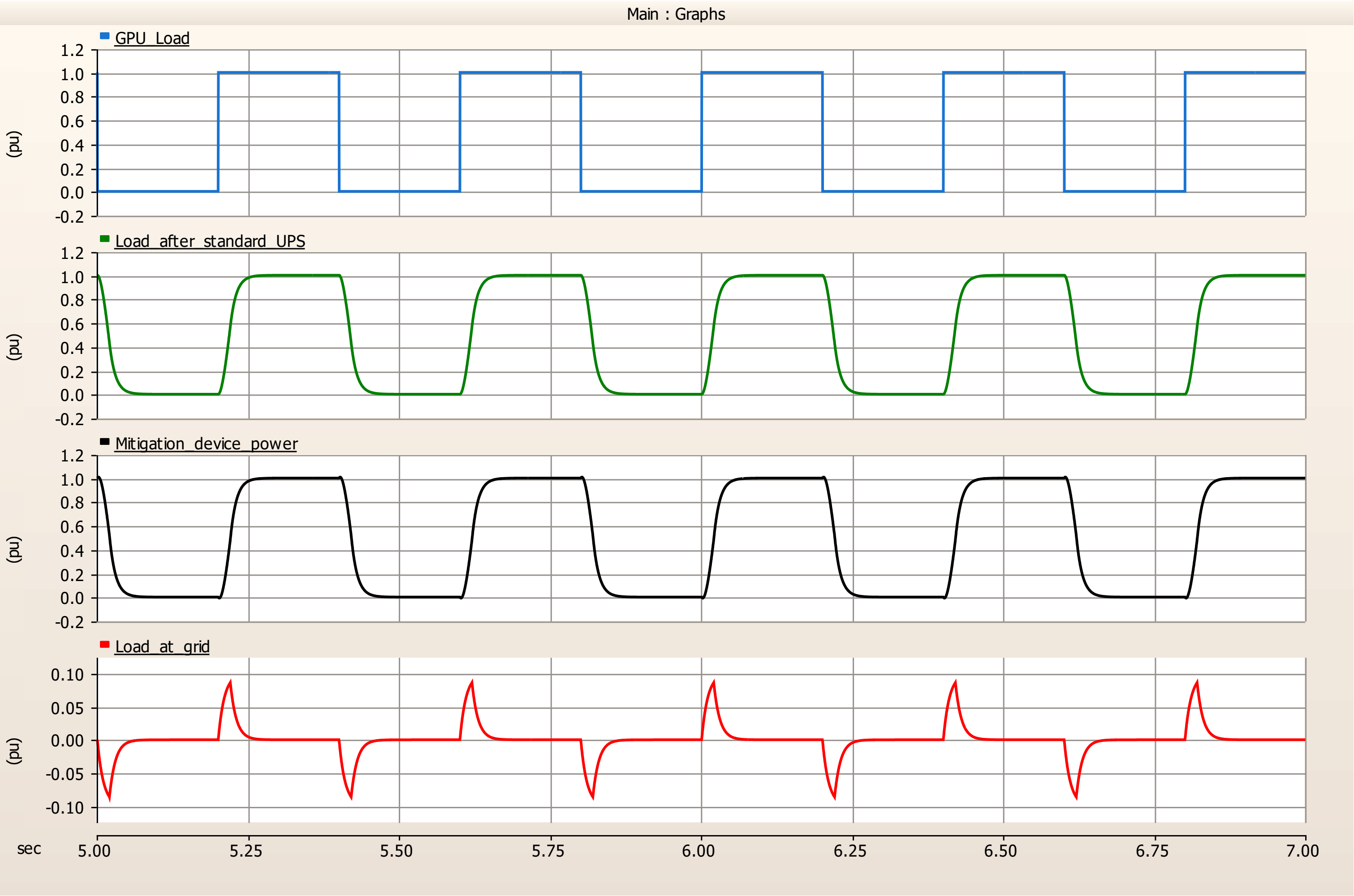
- **For active mitigation devices - response time related aspects**
  - Communications delays
  - Measuring delays
  - Processing delays
  - Filtering and Sampling rates
- **For passive mitigation devices - electrical impedances**
  - Grid impedance (system strength)
  - plant transformer impedances
  - Battery internal impedance
  - Lead impedances
- **Monitoring**
  - Instantaneous active power measurement with minimum filtering for sub synchronous frequencies is required
  - Phasor base active power calculations are not recommended

What directly impacts the effectiveness of a mitigation method



- Mitigation devices may not effectively compensate for high ramp-rate load variations due to response time limitations.
- High ramp-rate load variations can also cause DC bus voltage fluctuations in double-conversion technologies, allowing a portion of the load disturbance to propagate to the grid side (small but not zero).
- As a result, the load ramp rate assumed in EMT studies has a direct impact on compensation effectiveness and the magnitude of residual power disturbances at the grid interface.

Example mitigated load profile



Load power at GPU level

Power after UPS

Injection from mitigation device

Power at grid level (after mitigation)

Results Summary

No.	Mitigation Method	Technology Maturity	Energy Storage	Losses	Response Type	Response Speed	Load Compensation Efficiency	
							High ramp rates	Low ramp rates
1	GFM BESS	Mature	High	low	Natural (un-controlled)	Very fast	Low	Medium
2	BESS with active compensation	Relatively new	High	low	Active (controlled)	Medium	Medium	High
3	E-STATCOM	Relatively new	Medium	Very Low	Active (controlled)	Fast	High	Low
4	E-STATCOM + GFM BESS	Relatively new	High	Very Low	Both natural and active	Very fast	High	High
5	Double Conversion UPS (Low Voltage)	Relatively Mature	Low	High	Natural (un-controlled)	Very fast	Very High	Low
6	Double Conversion UPS (Low Voltage) + GFM BESS	Relatively Mature	High	High	Natural (un-controlled)	Very fast	Very High	Very high
7	Double Conversion UPS (Medium Voltage)	Relatively new	High	High	Natural (un-controlled)	Very fast	Very High	Very High
8	GPU Level Mitigation	New	Low	?	?	?	?	?

Questions?

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