

Mitigating AI Training Power Oscillations: Utility Requirements and In-Rack Power Filtering



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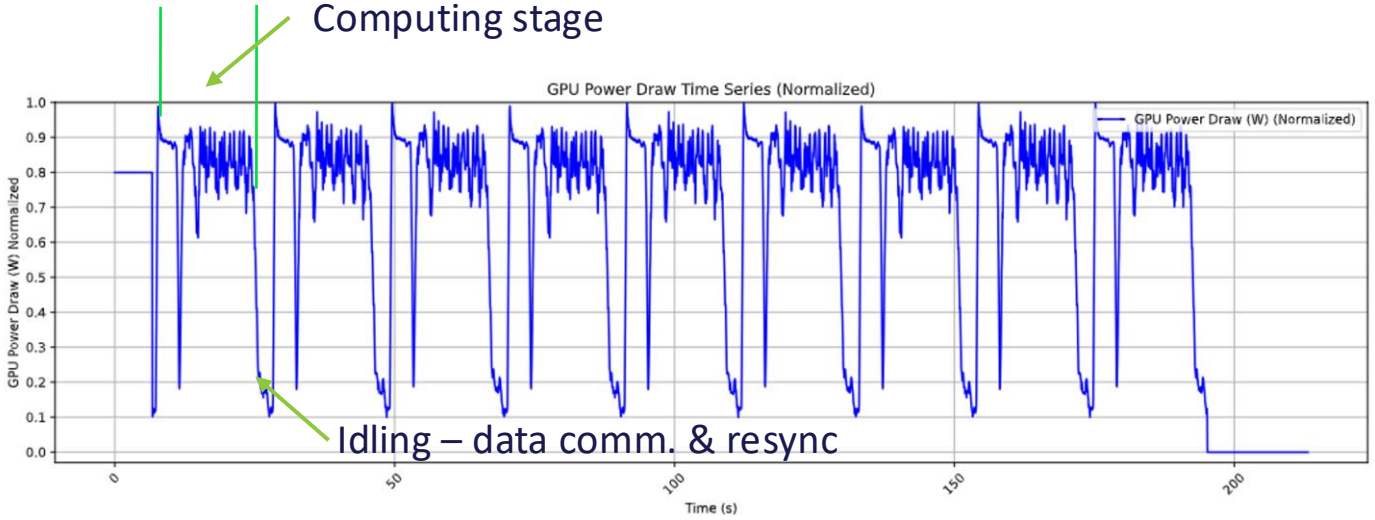
Luz Belmont *Microsoft*

Outline

- Workload characteristics of large AI training clusters
- Key power grid stability concerns
- Utility requirements for instantaneous active power at large datacenters
- System-wide synchronized monitoring framework
- Mitigation strategies used across the industry
- In-rack power filtering approach
- Call to Action

Large AI Cluster Training Workload

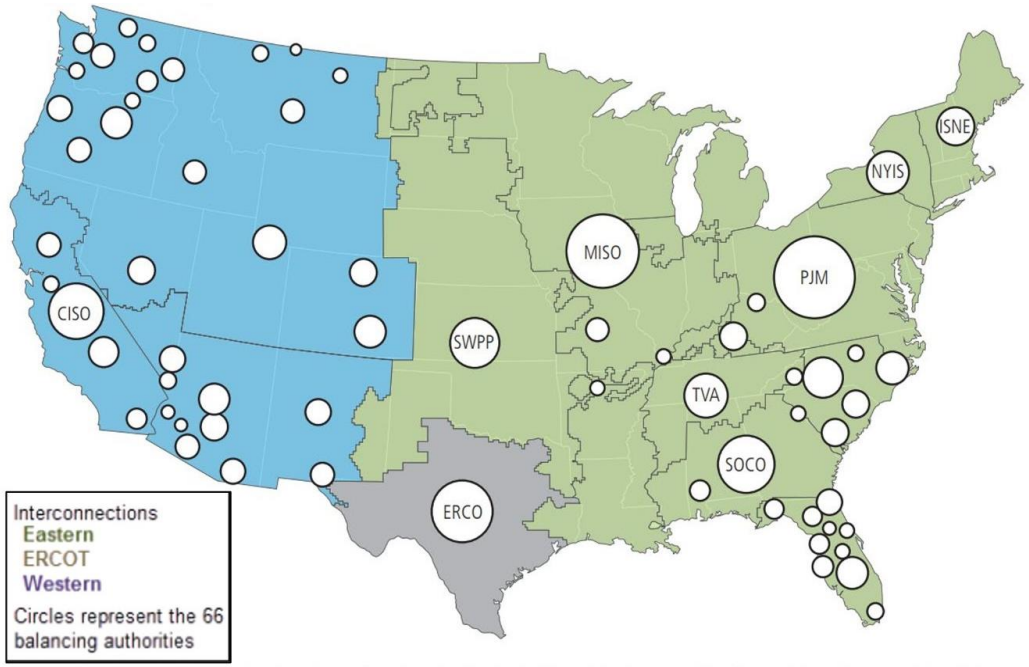
Typical AI Training Load Profile*



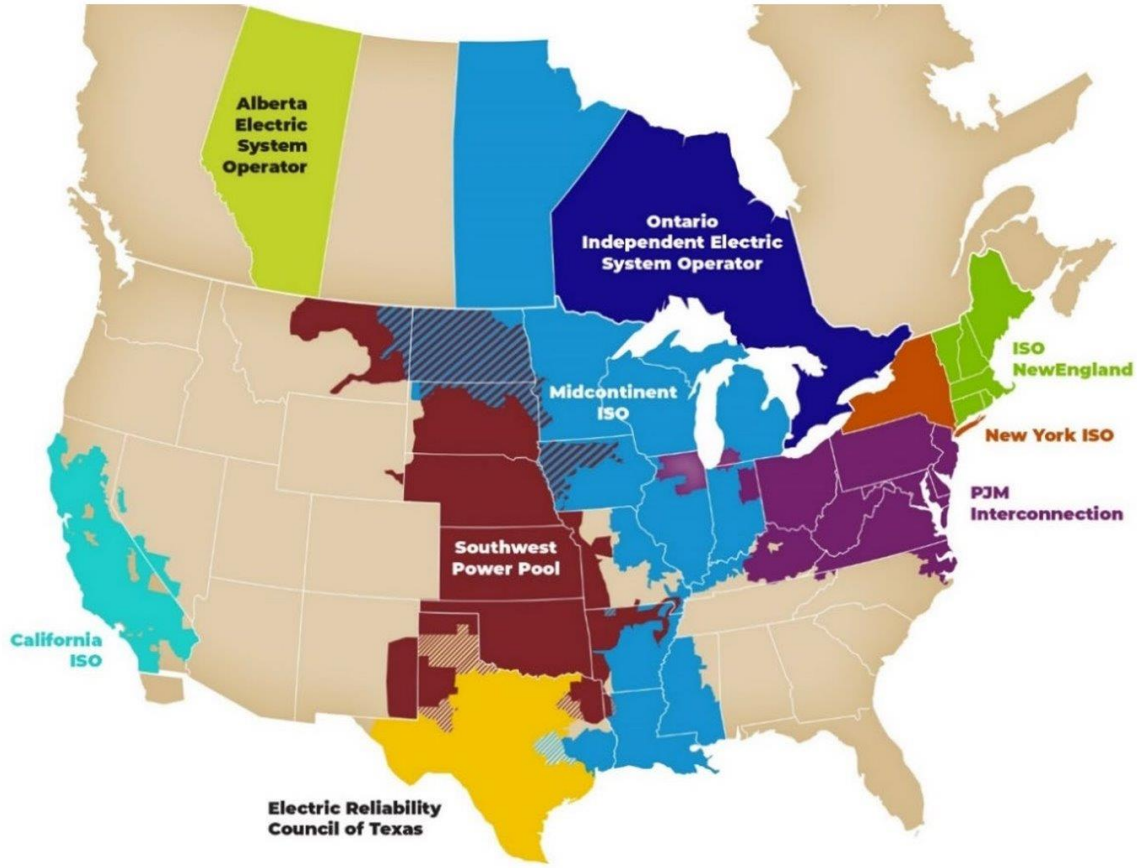
- Resonant frequencies in the bulk power system
  1. Inter-area oscillations: 0.1–0.5 Hz
  2. Regional oscillations: 0.5–0.8 Hz
  3. Local oscillation modes: 0.8–2 Hz
  4. Sub-synchronous and torsional oscillations: 5–55 Hz
- Traditional PSU bulk capacitance can attenuate power components above line frequency seen by downstream IT load

*Ref: Power Stabilization for AI Training Datacenters

North America Bulk Power System (BPS)



Source: Quadrennial Energy Review: Transforming the Nation's Electricity System: The Second Installment of the QER (January 2017)



Ref: [How it Works: The Role of a Balancing Authority]

Major Grid Concerns

1. Forced oscillations
   a) Inter-area oscillations – large-grid stability and blackout risk
   b) Regional oscillations – regional grid stability
   c) Torsional oscillations – turbine-generator shaft damage
2. Flicker
3. Grid–datacenter interface impedance stability (13–27 Hz)
4. Large grid disturbances
   a) AI training cluster (100s of MW to GW) start-up and shutdown
   b) Large load transfer during utility grid short-circuit faults

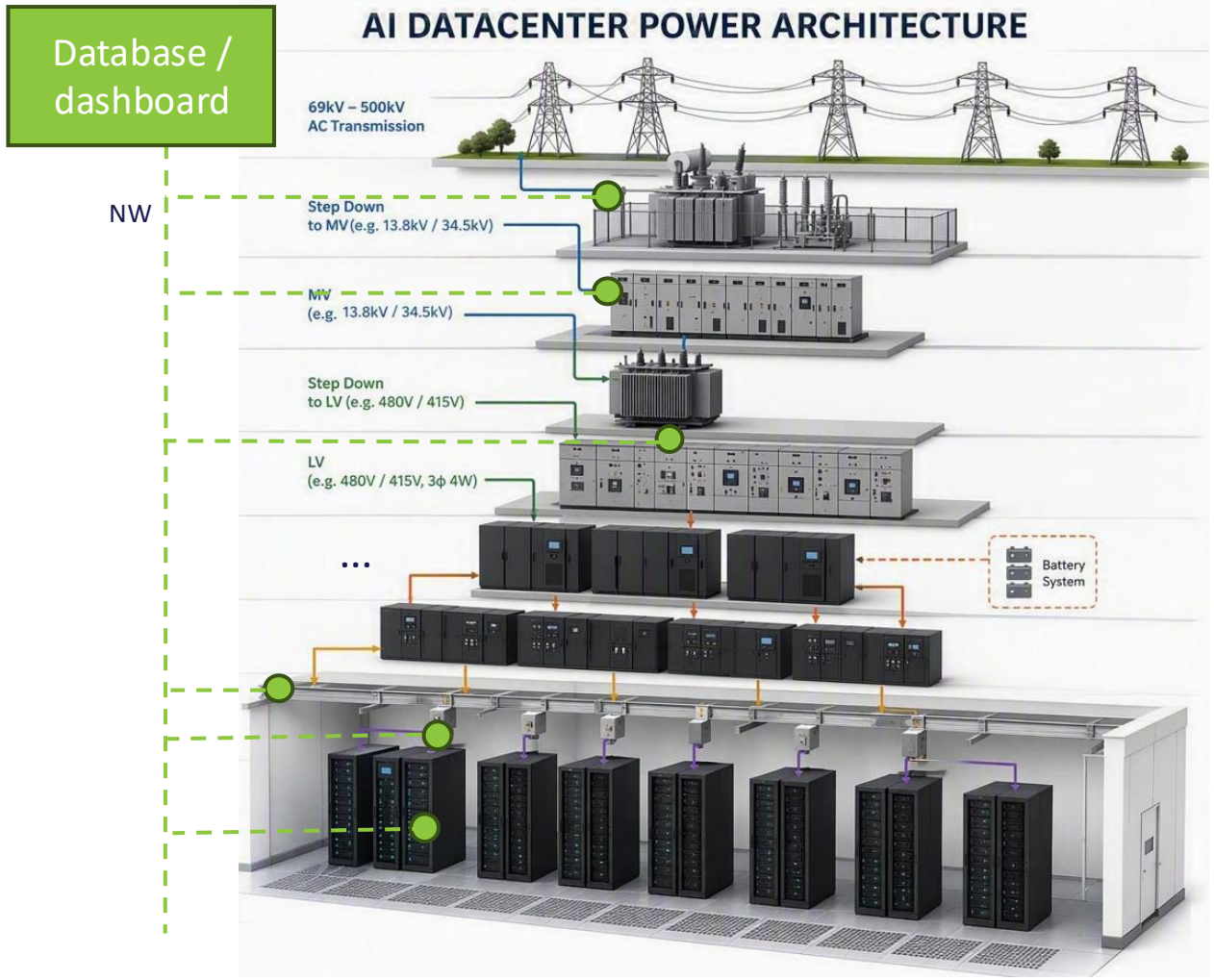
Utility Requirements for Large Loads

Active Power Intra-Minute Limit and Ramp Rate Limit

Region	Generation Capacity (GW)	Load Variability Limit (or proposed)	Ramp Rate Limit (or proposed)
MISO	~138 GW	10 MW per 5s sliding window	30 MW/min
ATC (in MISO)	-	25 MW per 5s sliding window No individual freq. exceeds 10 MW	30 MW/min
ERCOT	~105 GW	10 MW per 5s sliding window	-
SOCO (SBA)	~50 GW	10 MW for 0.1-5 Hz for single freq. 2.5 MW for 5-55 Hz for single freq. 10 MW per 4-6s for P75 1 MW for median change	20 MW/min
AESO	~23.4 GW	Originally 0.16 MW (study-based now)	10 MW/min
LIPA	-	20 MW for 0.1-5Hz range 10 MW for 0.1-5 Hz for single freq. 3.5 MW for 5-55 Hz for single freq.	20 MW/min

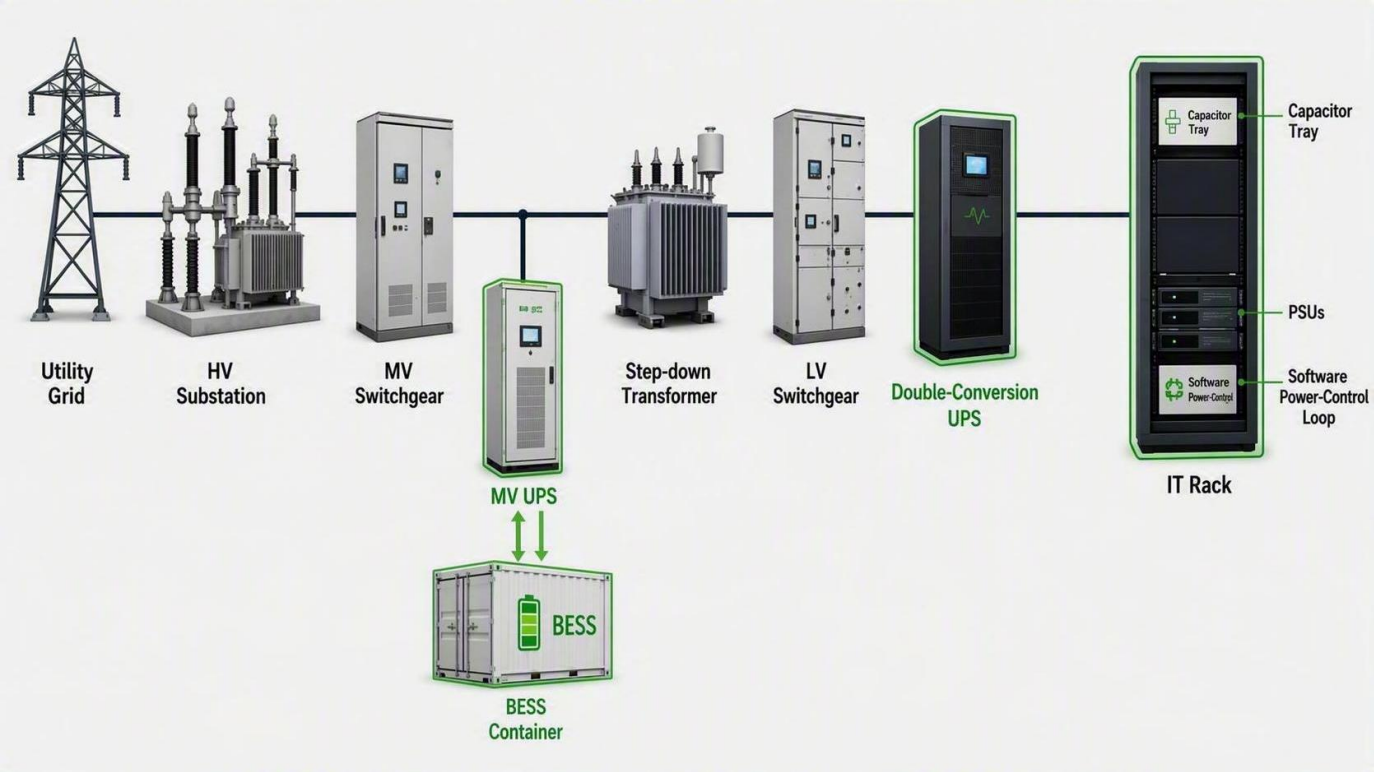
System-Wide Synchronized Monitoring Framework

- Synchronized, high-resolution measurements at strategic points to characterize AI workload dynamics
  1. **HV substation:** 100s of MW
  2. **MV switchgear:** 10s of MW
  3. **LV switchgear:** a few MW
  4. **Row**: 100s of kW to MW
  5. **Rack input**: 10s-100s of kW
  6. **IT chassis**: kWs

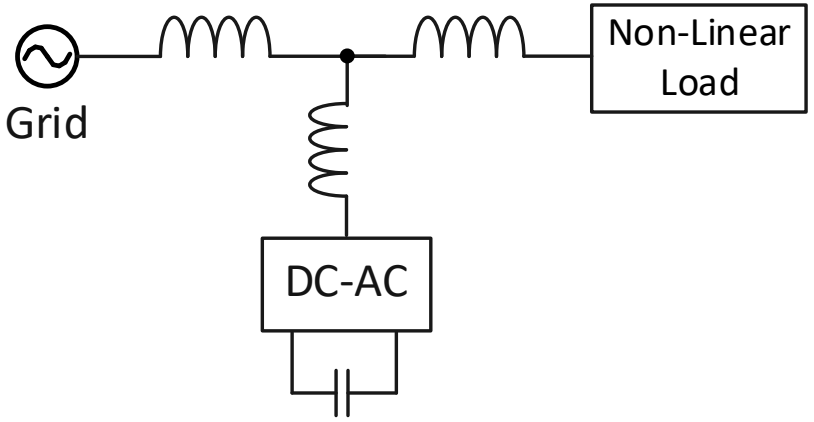


Major Mitigation Strategies in Industry

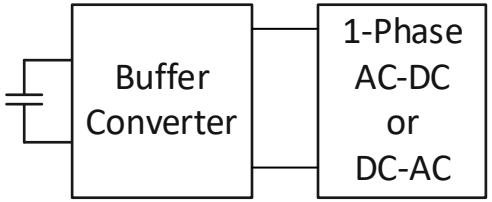
- HV / MV
  - MV UPS + BESS
- LV
  - LV UPS
- Rack
  - Capacitor tray
  - Software solution



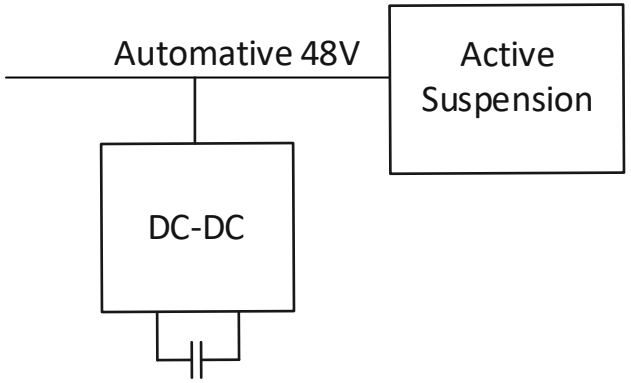
Power Filters with Capacitor: intuitive solutions from other industries



Active power filter for electric arc furnace (EAF) with rapid and unpredictable load.

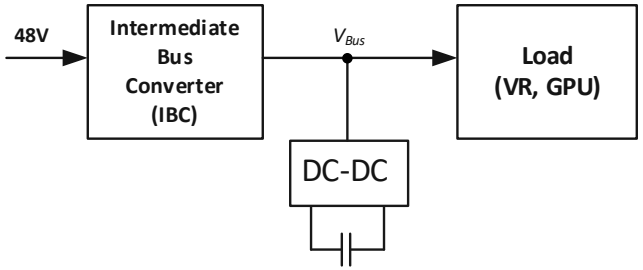


Energy buffer for double-line frequency power: Google little-box challenge 2014.

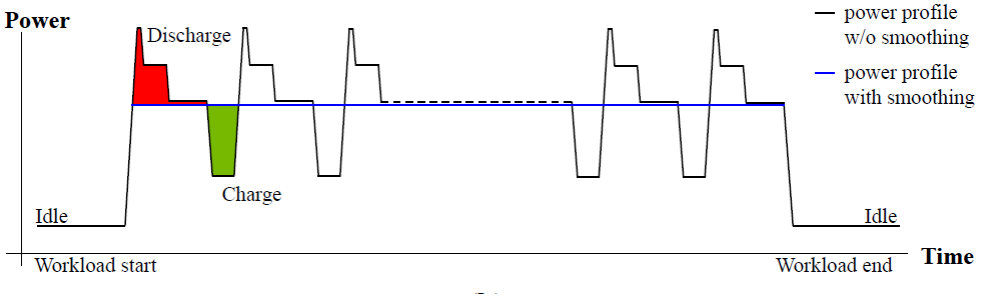


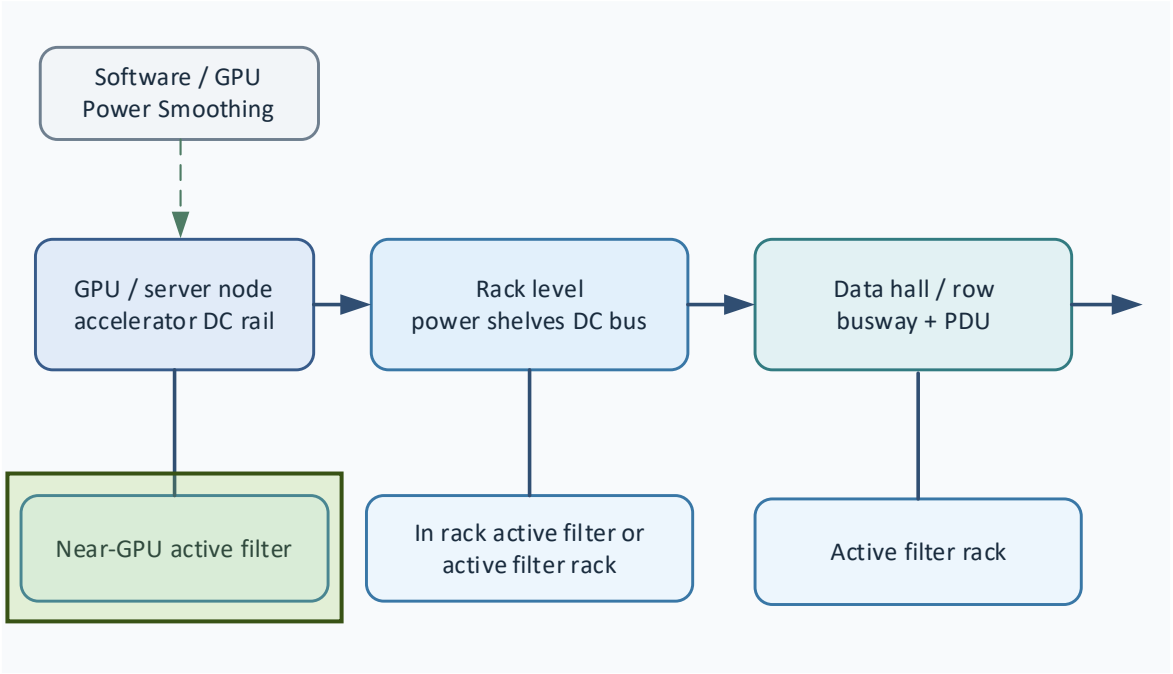
Energy buffer for active suspension system: Controller module for highly dynamic loads.

Power Filters with Capacitor: where to put them



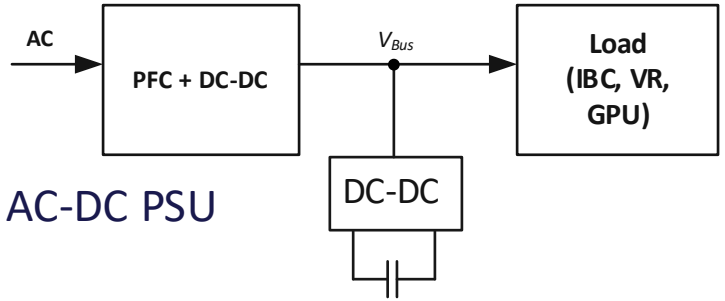
Figures from:
Lei Gu, APEC 2026

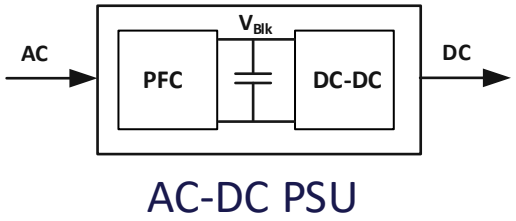




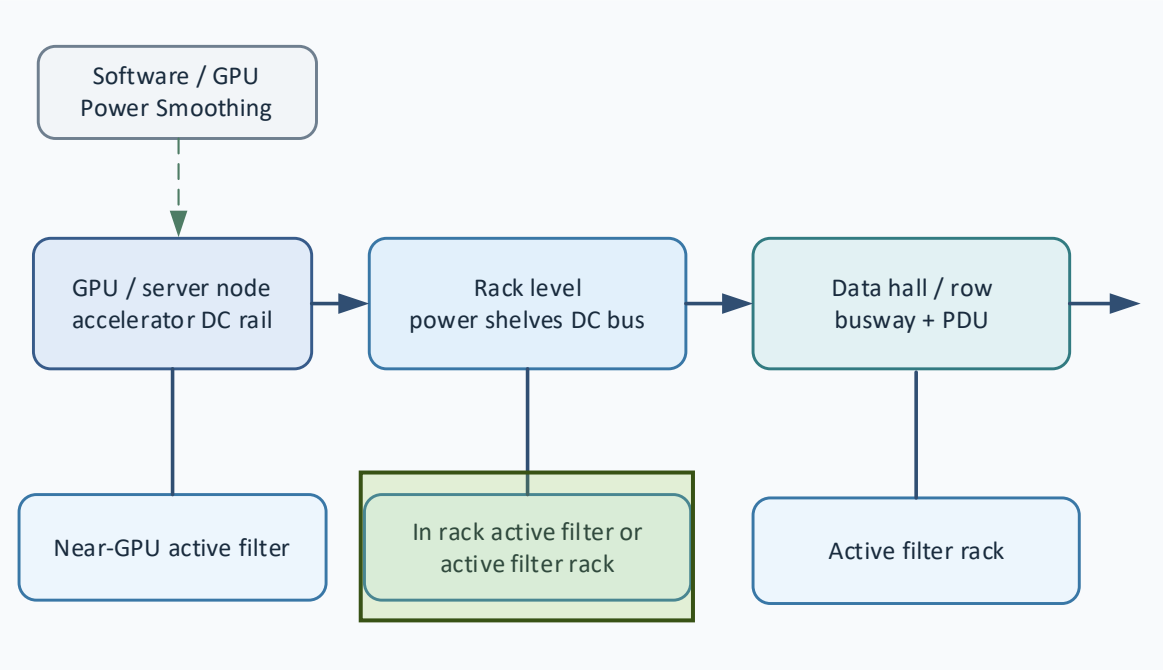
Power Filters with Capacitor: where to put them

[Power capacitor shelf (PCS), OCP 2024]





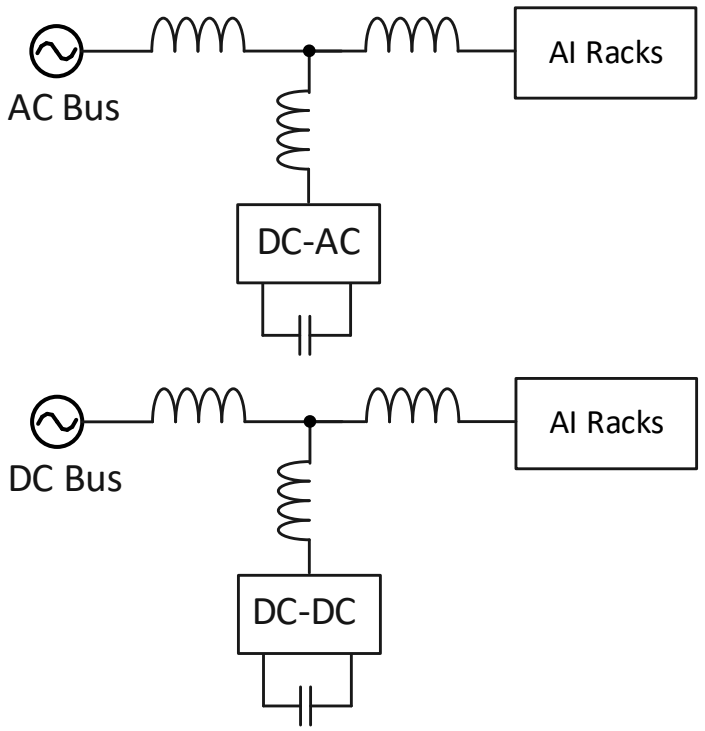
$$DoD = 1 - (V_{min}/V_{max})^2$$

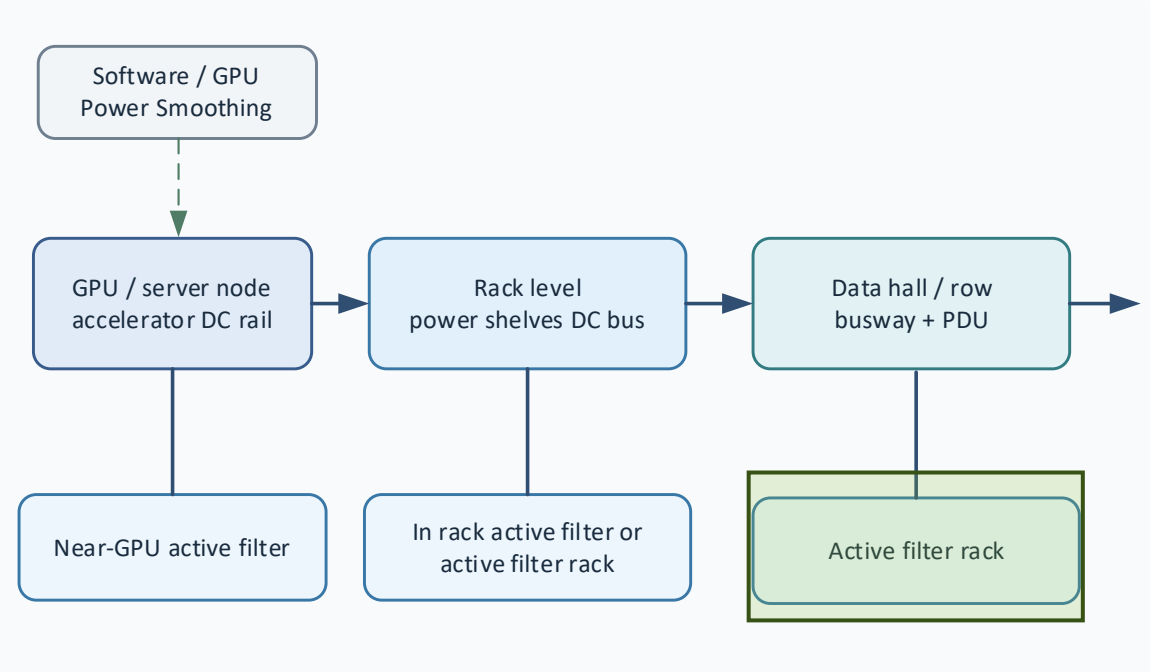


A natural soft bus inside the AC-DC PSU: V_{Blk}

1. Bulk capacitor's Depth of Discharge (DoD) is limited
   a) *AC voltage and component voltage rating*
2. Capacitor shelf/tray is a more attractive solution
   a) *Higher DoD*
   b) *Supercapacitors offer higher energy density than E-cap*
   c) *Careful coordination with the PSU is required*

Power Filters with Capacitor: where to put them

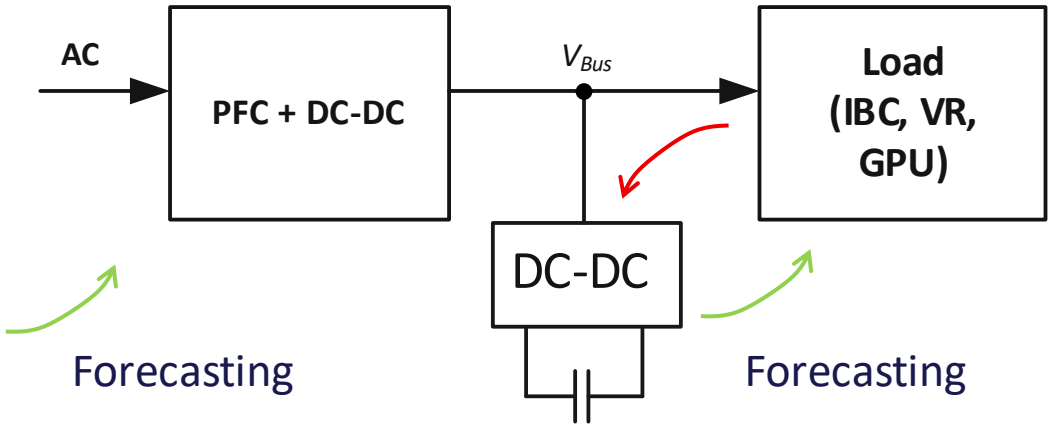


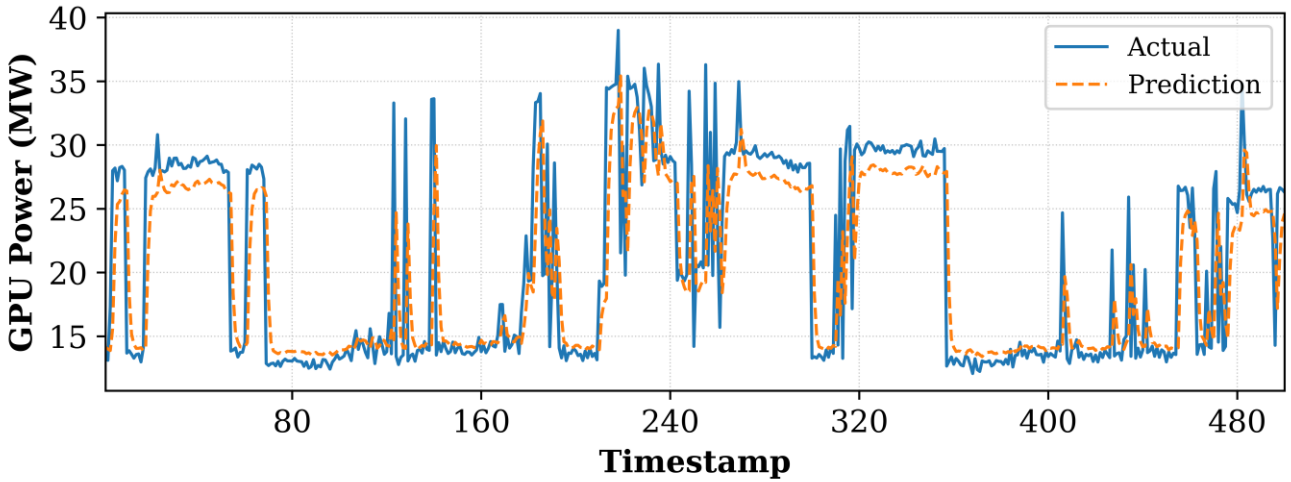


Busway level capacitor rack solution is not an ideal solution

1. Downstream components like PSU, IBC still suffers
2. Future DC bus way solution prefers capacitor shelf
3. Can be a patch solution for existing data centers

Smarter Way to Control for Power Filtering





Forecasting and coordination by power filter and GPU load

1. Help to prepare the charge and discharge positing
2. Upper stream UPS and BESS system can do the same for low frequency component filtering
3. GPU telemetry to power system deliver system is needed

'AI data center load forecasting: a liquid neural network approach,' Mariam Mughees, 2026, IEEE TRANSACTIONS ON SMART GRID

Call to Action

1. There is no technical blocker from power electronics point of view
2. Better capacitor technologies are needed to further push energy density
3. Smarter real-time forecasting algorithm is strongly desired
4. Standardized AI datacenter system-level synchronized monitoring framework
5. Collaborate through OCP to standardize AI workload characterization, synchronized monitoring, power-filtering performance metrics, and validation methods across rack, facility, and utility layers

Thank You!

