RACK & POWER



Hardware Mitigations for AI/ML Workloads Power Fluctuation

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OCP PLATINUM Member

From Data Center to AI Factor

- The rise of Cloud computing led to the development of “hyperscale data centers”
  - MW scale facilities housing tens of thousands of machines
  - Typical IT rack power 10-20kW
- Growth of AI/ML is transforming hyperscale data centers into AI factories
  - GW scale facilities optimized for the full AI application lifecycle from training to inference
  - ML rack power reaching 1MW and above!



Photo source

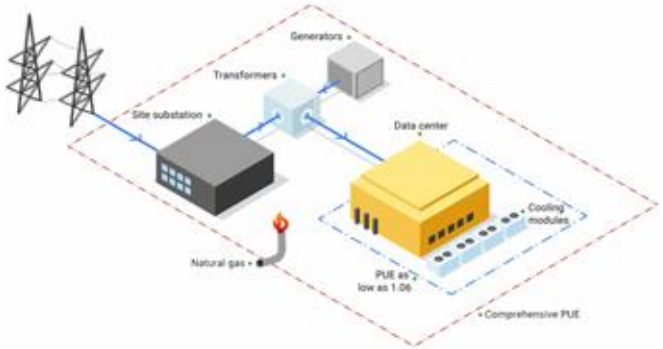
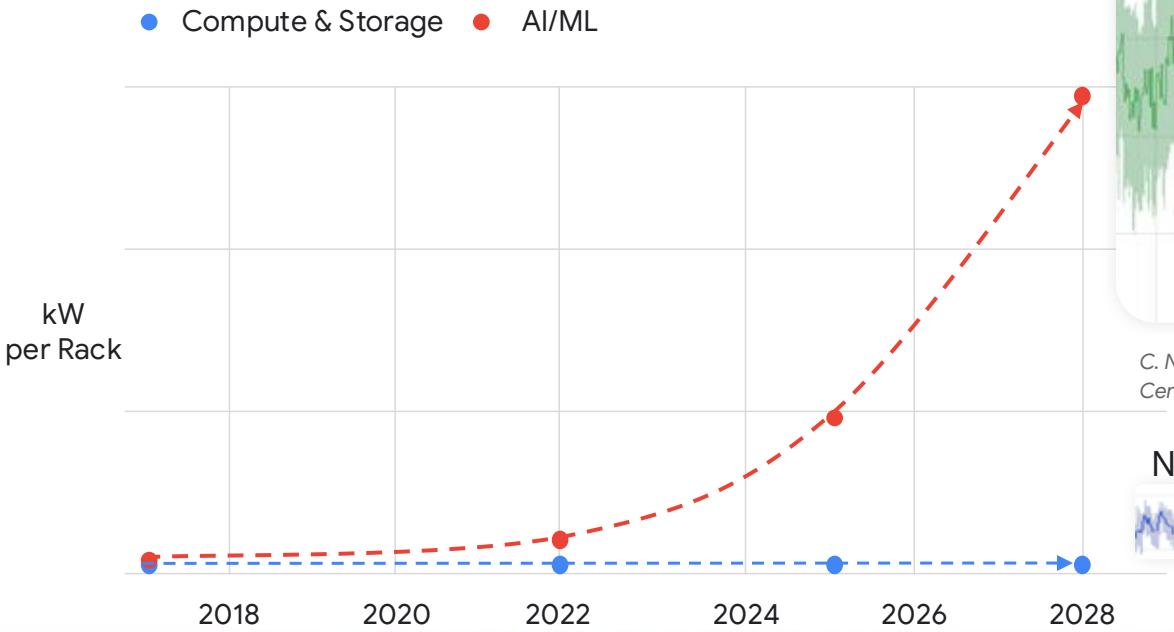


Image source

Challenges of AI/ML Workloads

Power Demand

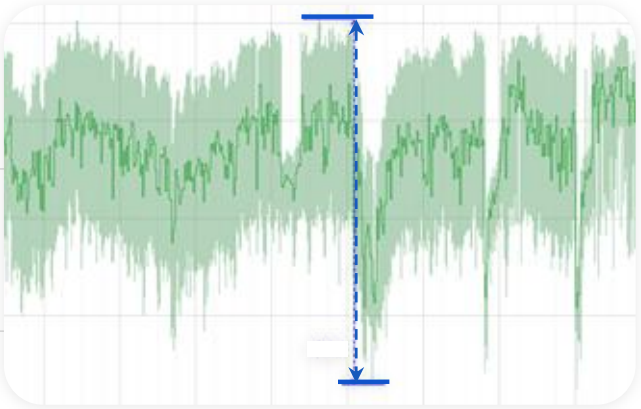
Accelerated power increase



Synchronized AI workloads

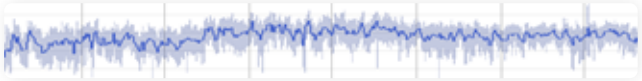
Data center and in-rack di/dt events

AI Workloads



C. Nge, M. Iyengar, "How AI/ML Workloads are Transforming Data Center Power and Cooling", APEC 2026

Non-AI Workloads



Infrastructure Impact: Datacenter & Utility Vulnerabilities

Large cluster-level swings (measured in MW) have critical operational consequences

Grid Instability & Utility Penalties

Exceeding utility ramp-rate limits (e.g., 20 MW/min) triggers Supervisory Control and Data Acquisition (SCADA) alarms, violates power quality standards (IEEE 519/1453 flicker), and risks facility disconnection.

Onsite Generators

Rapidly dropping a load can cause "load shedding" issues, risking generator tripping.

Datacenter Infrastructure

Thermal and mechanical stress on electrical busducts, transformers, and mechanical cooling systems.

Silicon Lifetime Impact

Severe temperature cycling on accelerators reduces their long-term operational reliability.

Software vs Hardware Mitigations: The Performance Trade-off

Mitigating Power Fluctuations: Software vs. Hardware



Software Controls (*Complementary Tool*)

Software controls serve as a key tool in the mitigation toolbox, enabling flexible workload-level management alongside hardware solutions.

- ***Intra-Job Smoothing*** (e.g., XLA ML WL): Dampens power variance by injecting synthetic compute, providing targeted workload stability.
- ***Power Capping & Sigkill***: Provides direct control bounds over peak power execution rates when grid demands require immediate throttling.

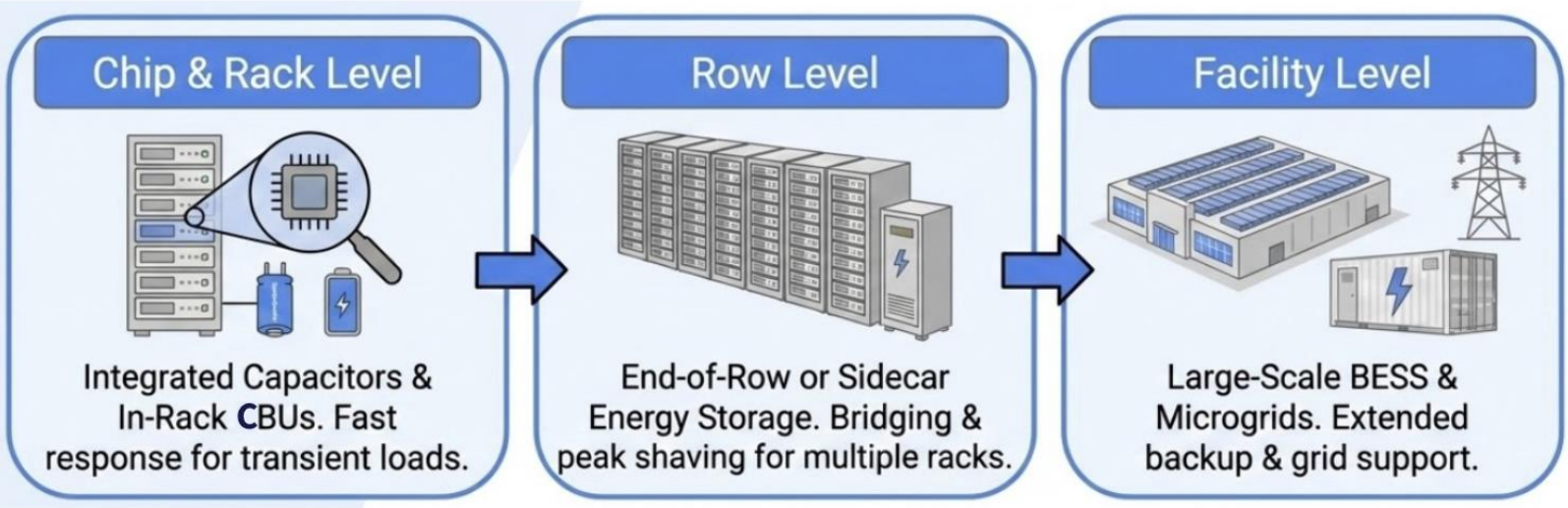


Hardware-Based Smoothing (*End-to-End*)

Eliminates performance penalties by letting workloads run flat-out at peak efficiency.

- ***Zero Performance Penalty***: Maximizes hardware capabilities, enabling continuous execution at peak efficiency.
- ***Local Energy Buffering***: Dampens the physical load locally to present a "smooth" power profile back to the utility grid and generators.

Energy Storage Solutions for AI/ML Data Centers



Managing the dynamic power demands of AI/ML workloads requires highly responsive, full-stack energy storage. Rather than a 'one size fits all' approach, a 3-tier solution tailored to different response timescales guarantees power resilience.

Energy Storage Challenges

Coexistence of power supply and energy storage modules

Challenge: Advanced power systems require parallel, non-conflicting control of multiple power sources in a single power domain.

01

The Coexistence Challenge

PSUs, Battery Backup Units (BBU), and Capacitor Backup Units (CBU) must operate in parallel on a common high-voltage/low-voltage DC bus: supply management, deployment speed, regulations, etc.

02

Transient Coordination

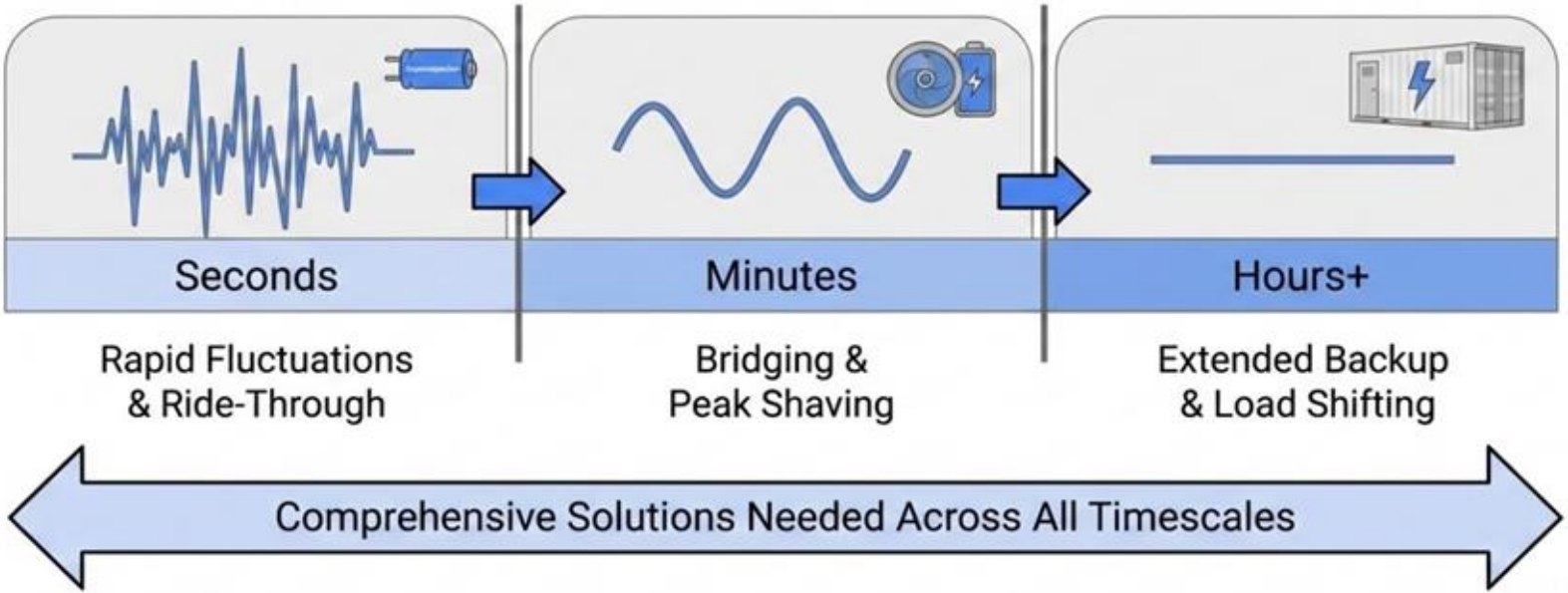
A power plane configuration where the CBU actively handles dynamic load transients while the BBU remains passive until AC failure presents integration and stability challenges.

03

Current-Sharing (I-Share)

Combining current-sharing signals (Ishare_PSU, Ishare_CBU, and Ishare_BBU) into a single peak-shaving controller that prevents control loop oscillations.

Energy Storage Challenges



An optimization strategy: Minimize energy storage requirements and EDLCs at the payload rack by utilizing dual-function energy storage modules to manage both (1) critical power bridging/backup and (2) workload power smoothing. Hours+ backup on the AC-side can be addressed using a Battery Energy Storage System (BESS) or alternative backup solutions.

Energy Storage Technologies

Evaluating Energy Storage for High-Power, High-Temperature and High-Cycle Applications ***supporting both BBU and CBU*** use cases.

Key Takeaway: Traditional batteries are unsuitable for high-frequency ML cycles (~1 million/year); ***hybrid supercapacitors, advanced Li-ion cell chemistries, emerging non-Li Tech could be promising candidates***.

Lithium-Ion (LFP) Batteries

Safer but limited cycle life (~3k to 10k cycles).

Requires massive oversizing to survive ML cycling.

Advanced Chemistries

LFP/NMC pairing with advanced metal oxides anode.

Sustainable materials: Na, Zn, HSB/C, etc

Emerging Tech, Time-to-market.

Electrolytic Capacitors

Exceptional power density and low Equivalent Series Resistance (ESR).

Virtually infinite physical cycle life (>5M+) but for only for short burst.

Lithium-Ion Supercaps

Hybrid approach. 4–5x higher energy density than EDLC with high power.

Slightly lower cycle life, higher cost, not sufficient energy for backup use-case.

Key Challenges: Supply Chain Management, Product Safety, Time-to-Market

Industry Product Concepts

Energy storage module supporting both BBU and CBU use cases, paired with rack-level EDLCs for ultra-high-frequency ride-through.

01

Sidecar/Row Level

Combined B/C BU

Must operate in parallel on a common DC bus.

02

Row Integration

I-Share Integration

Combining current-sharing signals into a single controller prevents loop oscillations.

03

10-Year Lifespan

100M+ Cycles

Achieving hundreds of millions of cycles over a 10-year span to engage and guide.

04

Decentral Control

DC Bus Signaling

Eliminating high-speed communication lines simplifies system integration.

05

Supply Chain

Souring

Multiple technologies and sources to achieve the given set of specifications at the best Perf/TCO.

[Call to Action] Building a Standardized OCP Ecosystem

- Where to find additional information (URL links)
  - Mailing list: dcf-energy@OCP-All.groups.io

- Problem to solve
  - Cooperatively develop and open-source high-voltage hybrid Battery/Supercapacitor module standards specifications within the OCP ecosystem at sidecar or row levels.
- Get involved
  https://www.opencompute.org/community/energy
- Timeline for contribution availability: next 2-3 quarters

Thank You!

