Dynamic Data Center Models to Enhance Grid Stability and Reliability

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Motivation: Data center power ramping and grid reliability

Large AI data centers exhibit rapid, correlated power fluctuations

- Power ramps occur at sub-second to minute timescales

- Utilities are concerned about voltage stability, equipment stress, and protection behavior

- Current planning models treat data centers as passive loads
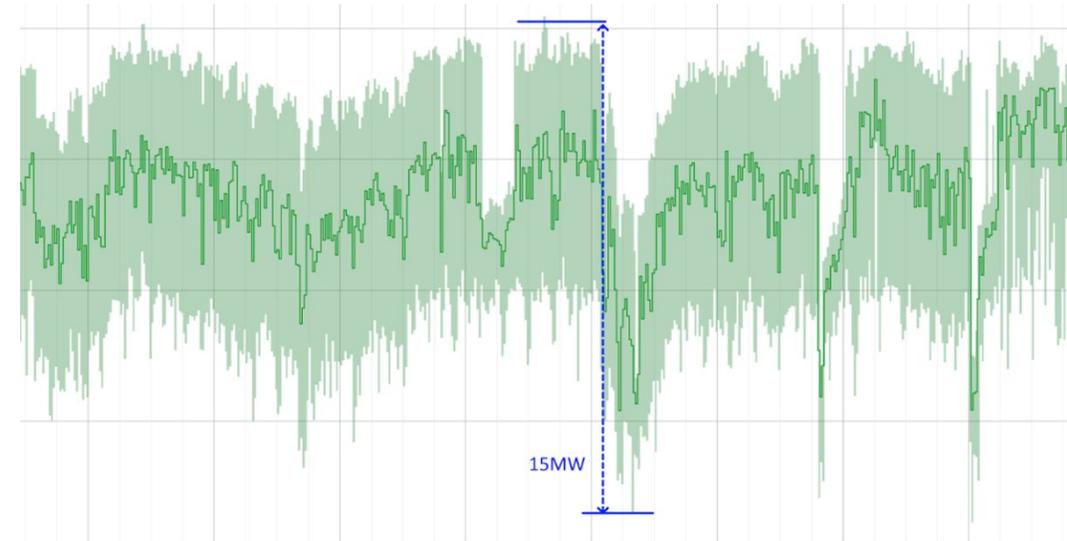
Large power fluctuations observed on cluster level. Source: Google

## Existing data center EMT modeling capabilities

- PSCAD-based models capture AI load dynamics and UPS behavior
- Recent work focuses on LVRT, fault response, and ride-through
- Energy storage is primarily modeled for backup and disturbances
- Power volatility is observed but **not actively controlled**
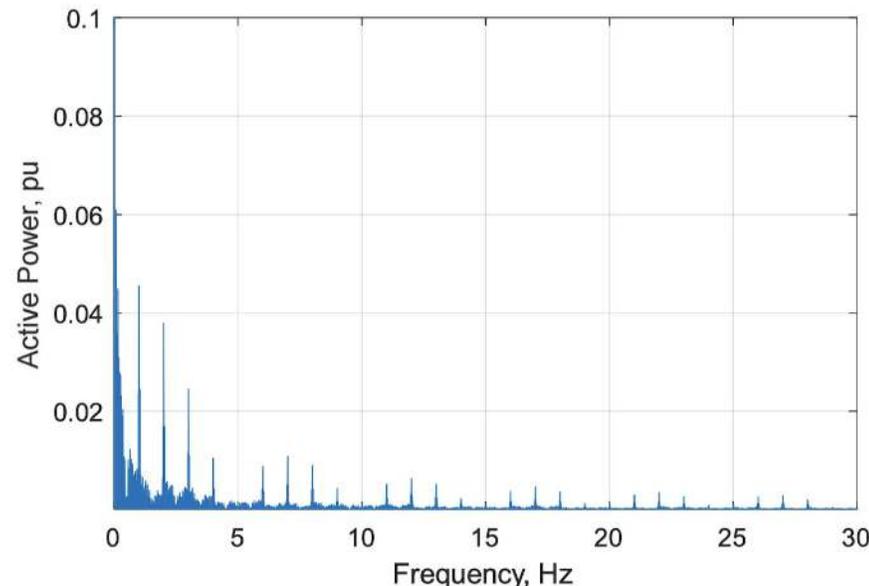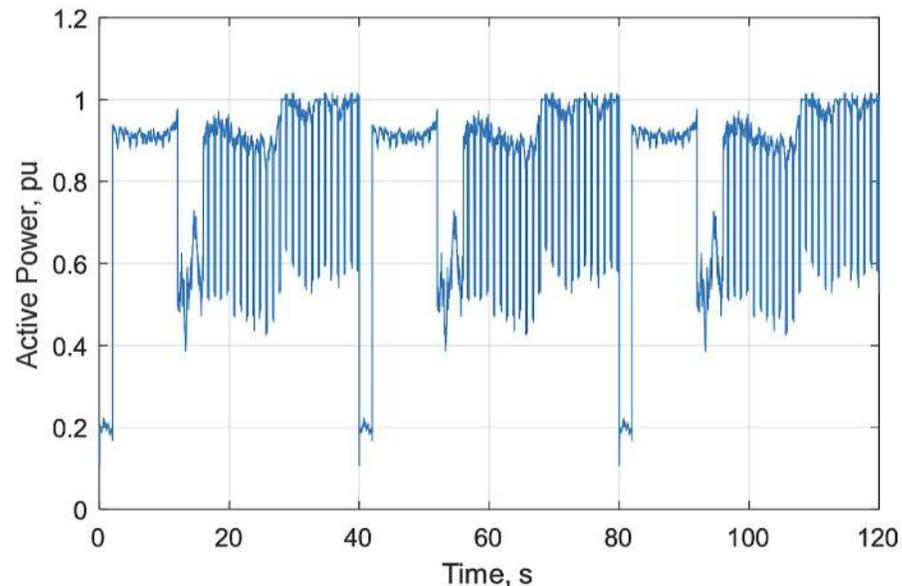
Exemplar load profile of AI training

Limitations of current approaches

- No quantitative definition of acceptable data center power volatility
- No control strategies designed for continuous power smoothing
- ESS not sized or operated for volatility mitigation
- Protection studies must assume worst-case load behavior
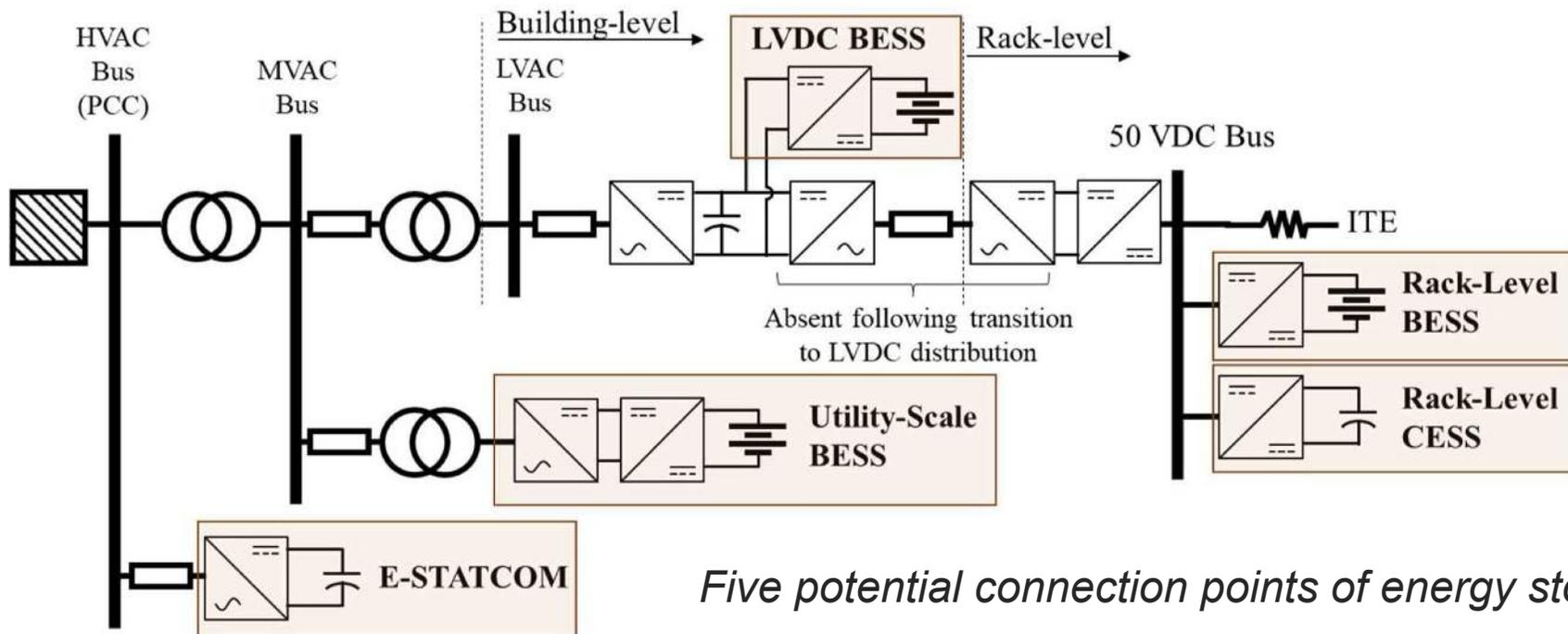
Five potential connection points of energy storage systems

MVDC data center as a controlled grid interface

- Model an MVDC data center architecture in PSCAD
- Integrate Li-ion BESS and microturbine DERs at the DC bus
- Use the DC bus as the primary interface to the grid
- Objective is to regulate grid-side power despite internal variability

Proposed MVDC data center modeling framework

- Modular study unit: **25 MW data center block**, scalable by replication

- Proposed two-stage DC architecture:
  - AC interface at PCC feeding rectification to DC distribution
  - **800 V DC distribution bus** supplying racks via DC/DC conversion
  - **5 to 50 V DC** at IT equipment level

- Average-value models for system-level studies at **50 µs+** timestep

- Load modeling approach:
  - Baseline power traces derived from **Open Compute Project** data
  - Superimposed **AI training waveform logic** consistent with PNNL load characterization

- Power volatility metrics at the PCC (proposed):
  - Ramp-rate metric: **95th percentile of |ΔP|** over **1 s**, **10 s**, and **60 s** windows
  - Variance metric: standard deviation after **1 Hz** (fast) and **0.1 Hz** (slow) low-pass filtering
- Proposed performance target:
  - Reduce each selected volatility metric to **≤ 10% of baseline**
- Reliability and protection sensitivities (proposed):
  - Study behavior across **SCR = 2, 5, 10** to represent weak to strong grid conditions
  - Examine interactions between smoothing control, current limiting, and fault recovery
- Intended outcome:
  - EMT-level insight into how controlled DC architectures alter grid-side stress and protection-relevant dynamics