Megapack

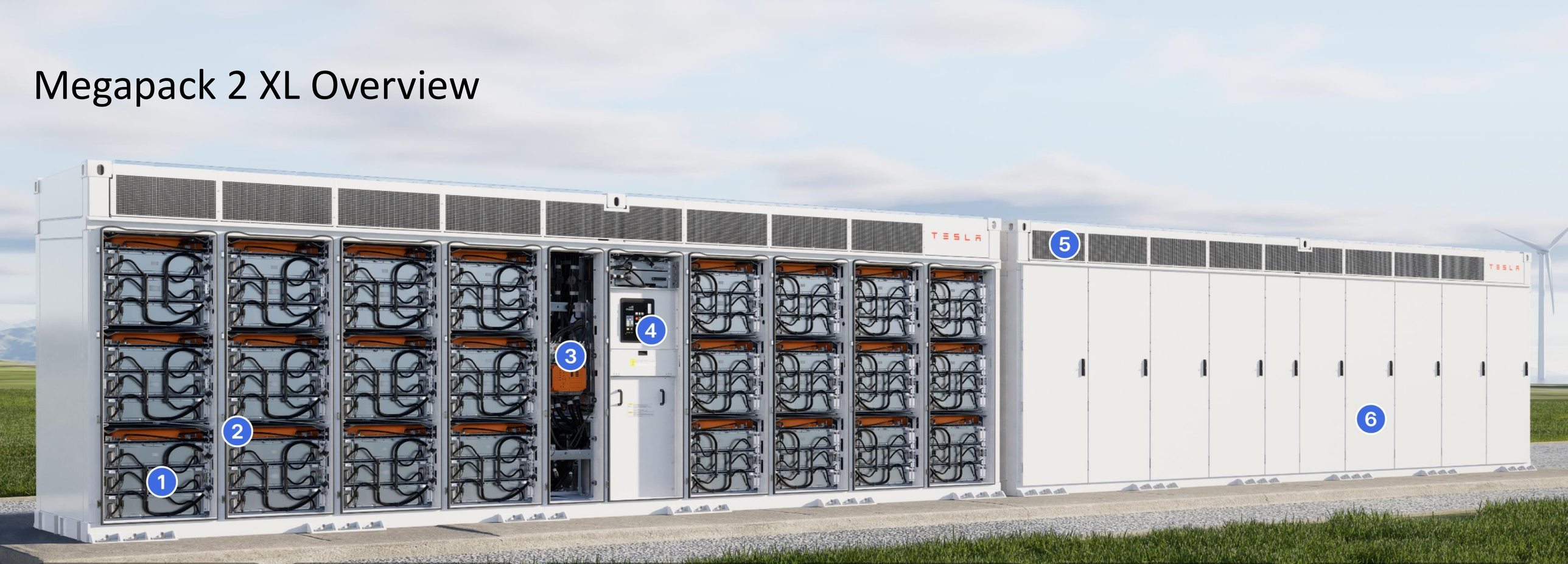
Battery Storage Applications at Data Centers

ERCOT Large Load Working Group
May 2025

Agenda

- Introductions
- Battery Storage Use Cases at Data Centers
- Example Projects – Megapacks Co-Located with Large Loads
- Questions

Megapack 2 XL Overview



1. AC Battery Modules (x24)
2. Grid-Tied Inverter (x24)
3. Thermal Cabinet Cabinet
4. Customer Interface (AC Breaker)
5. Thermal Roof
6. IP66 Enclosure

2 MW / 4 MWh
Per Unit

200 MW / 400 MWh
Per Acre

Battery storage use cases at data centers

- Load smoothing, focus on AI training
- Low voltage ride through (LVRT) support
- Load shaping for flexible utility connection
- Backup power

“Today’s problem is dealing with extreme power jitter…

We are having some power fluctuation issues, when you do synchronized training it’s like having an orchestra and it can go loud to quiet very quickly, at the sub-second level. The electrical system freak out about that – with 10-20 MW shifts several times per second.”

- Elon Musk
  August 2024 in conversation with Lex Fridman about xAI Memphis data center

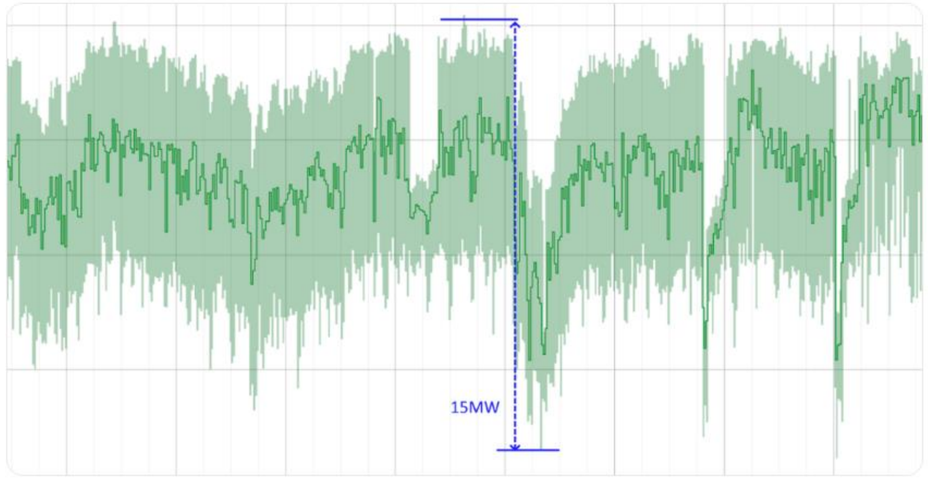


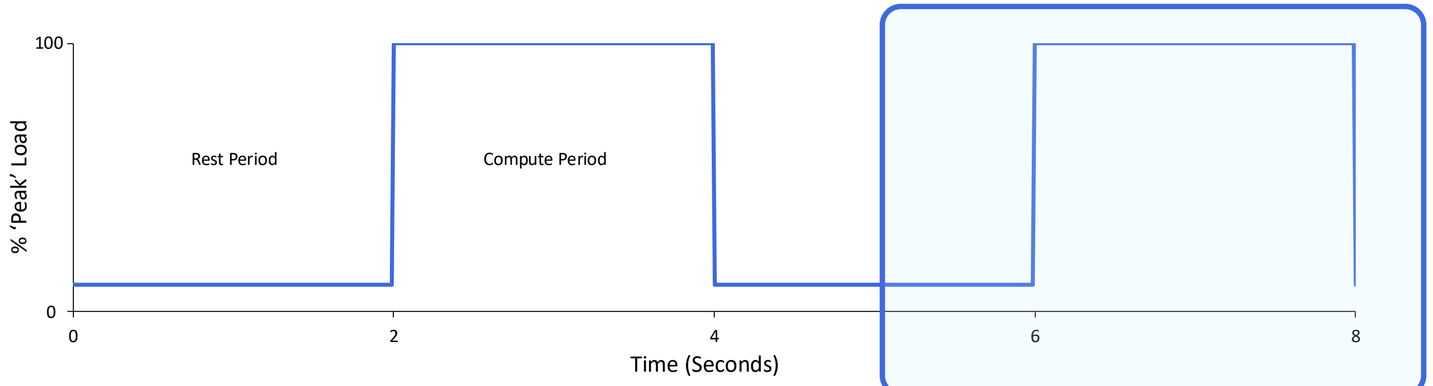
Fig. 1. Large power fluctuations observed on cluster level with large-scale synchronized ML workloads

“In our latest batch-synchronous ML workloads running on dedicated ML clusters, we observed power fluctuations in the tens of megawatts”

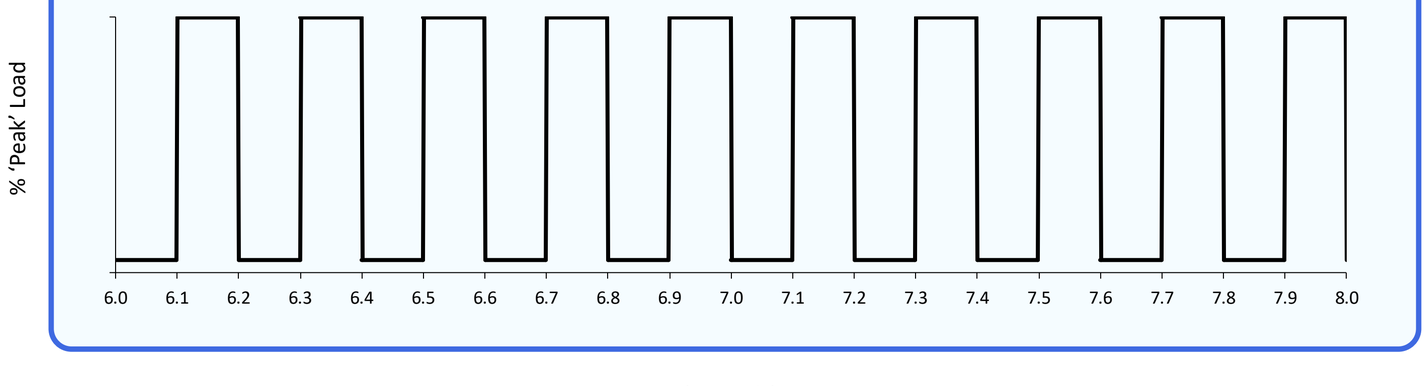
- Google Technical Lead Manager and VP, Engineering
  February 2025, Blog Post

Challenge: Power load fluctuations at AI training data centers

1 Measuring AI loads at ~second scale many see variations



2 'Compute' periods at millisecond scale can show step changes



Common characteristics of reported AI training power loads include

1. "Slow" seconds scale variations (0.1-1 Hz)
2. "Fast" millisecond scale variations (5-30 Hz)

Up to 90% power demand fluctuations
(100% -> 10%)

Impact of Load variation

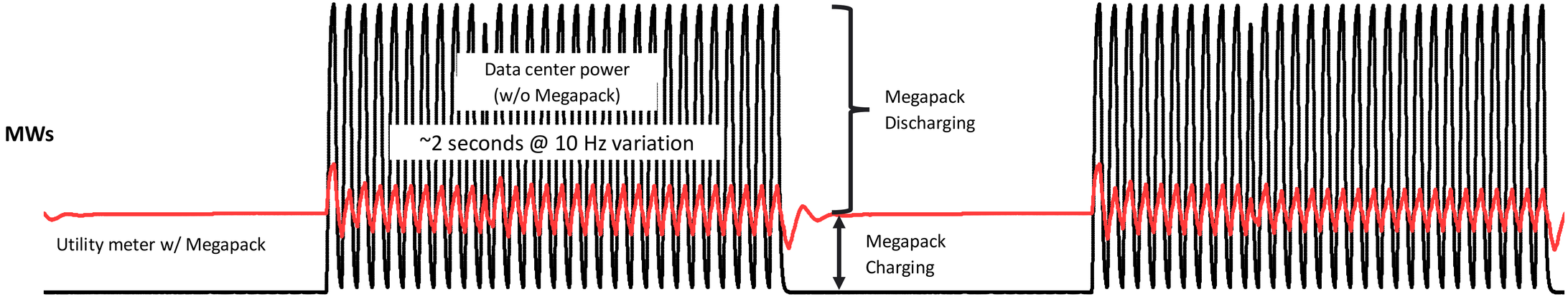
Off-Grid/backup (onsite generators)

- Generator oscillations beyond specification

On-Grid

- Voltage flicker
- Nearby generator interactions
- Frequency regulation challenges and inter-area oscillation excitation

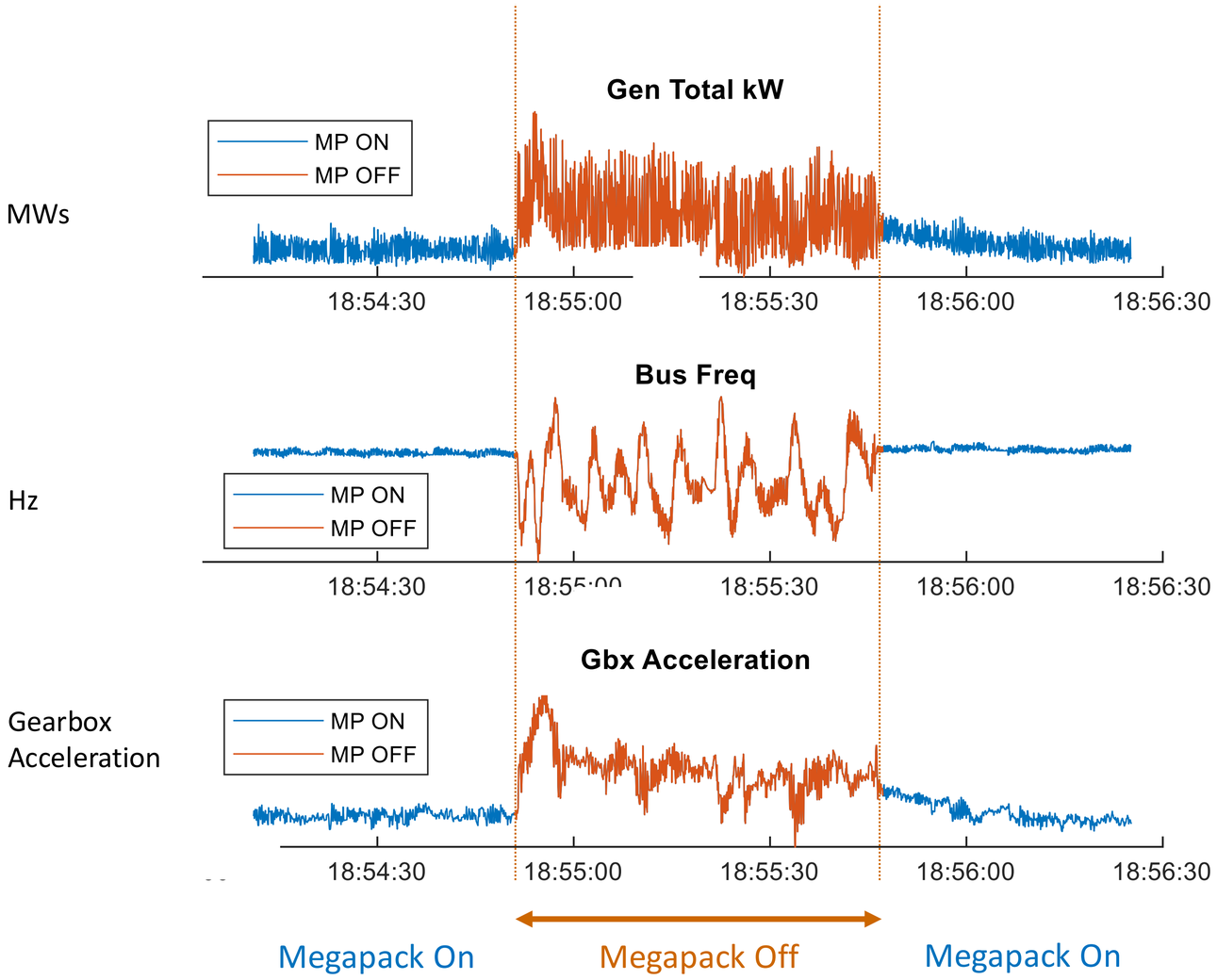
Solution: Load Smoothing with Megapack can reduce 70%+ of variability



Connecting Megapack in parallel to the load helps reduce variability → Improves grid reliability & power quality

- Energy throughput modeling shows 20+ year lifetime
- Charging and discharging are balanced such that BESS SOC is maintained for a 24/7 smoothing operation

Real-world results of AI training power load smoothing tested beyond 25 MWs



Power

Power generator highly variable without Megapack

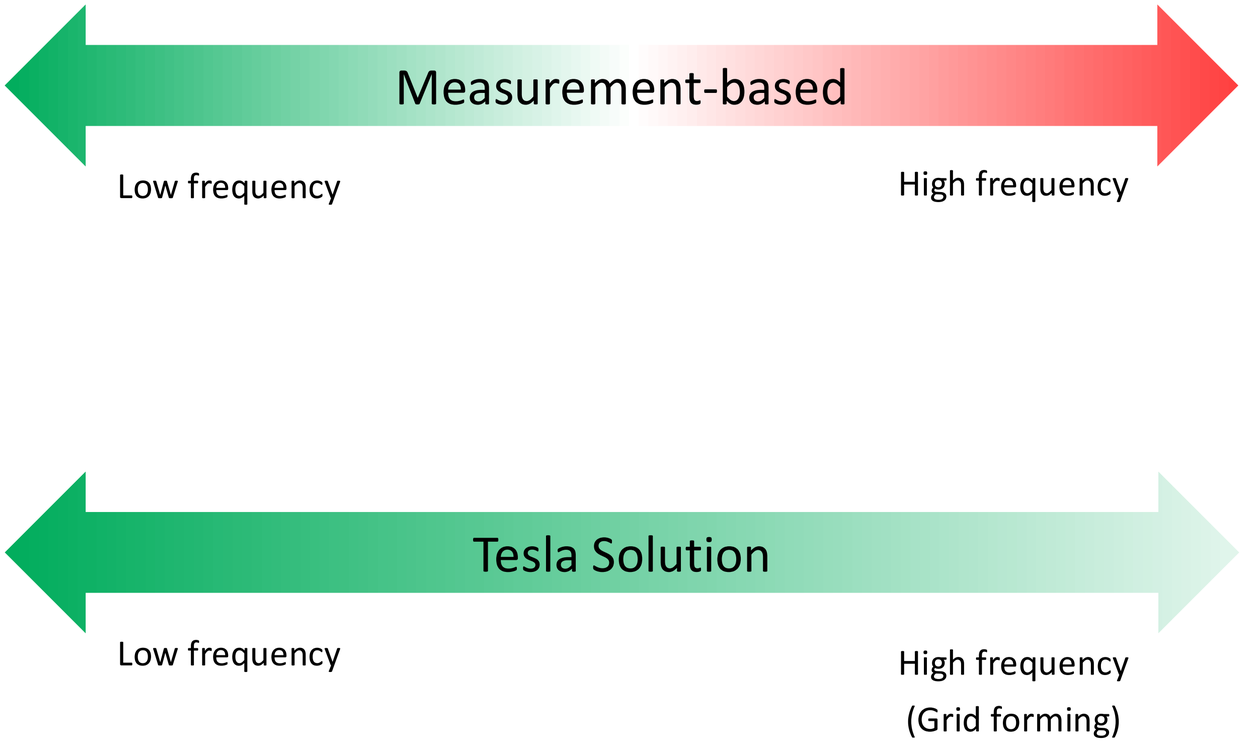
Frequency

Controls too slow on generator to compensate accurately for power variability

Mechanical

Generator bearing displacement

Control options of load smoothing



Measurement-based

- Measures the load variations and commands storage to respond
- Effective for low-frequency variations
- Not effective for high-frequency variations due to control delays

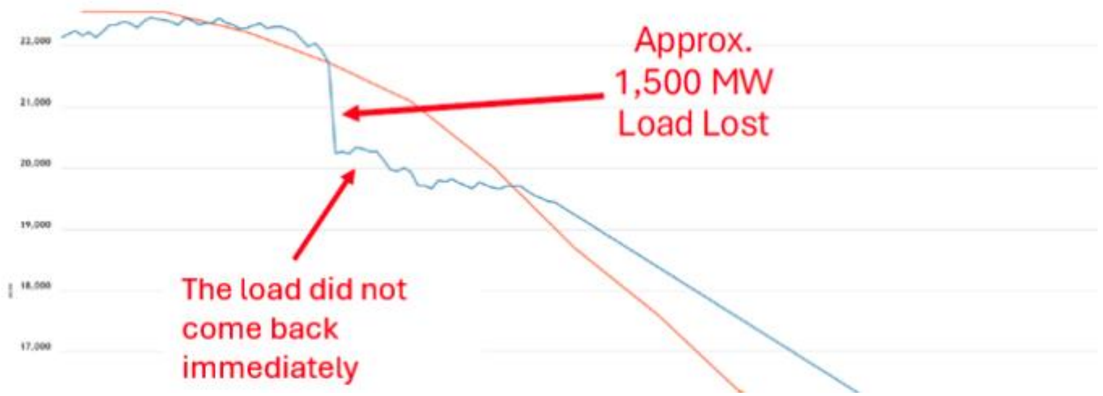
Tesla Solution

- Measurement based & Grid-forming controls used
- Effective for low-frequency variations
- Reduces high-frequency variations (70%+) based on impedance split with Grid-forming controls
- Can provide multiple services simultaneously

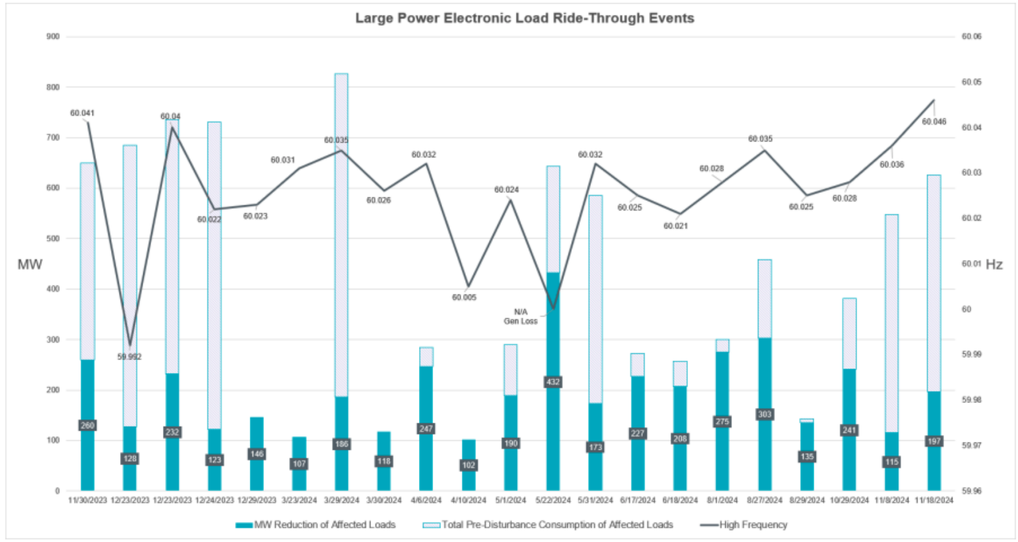
Challenge: Low Voltage Ride Through (LVRT) of data centers

Dominion: 1.5 GWs across 60 data centers

July 2024 – due to reclosing attempts on faulted 230 kV system



ERCOT: Many events of 100s of MWs



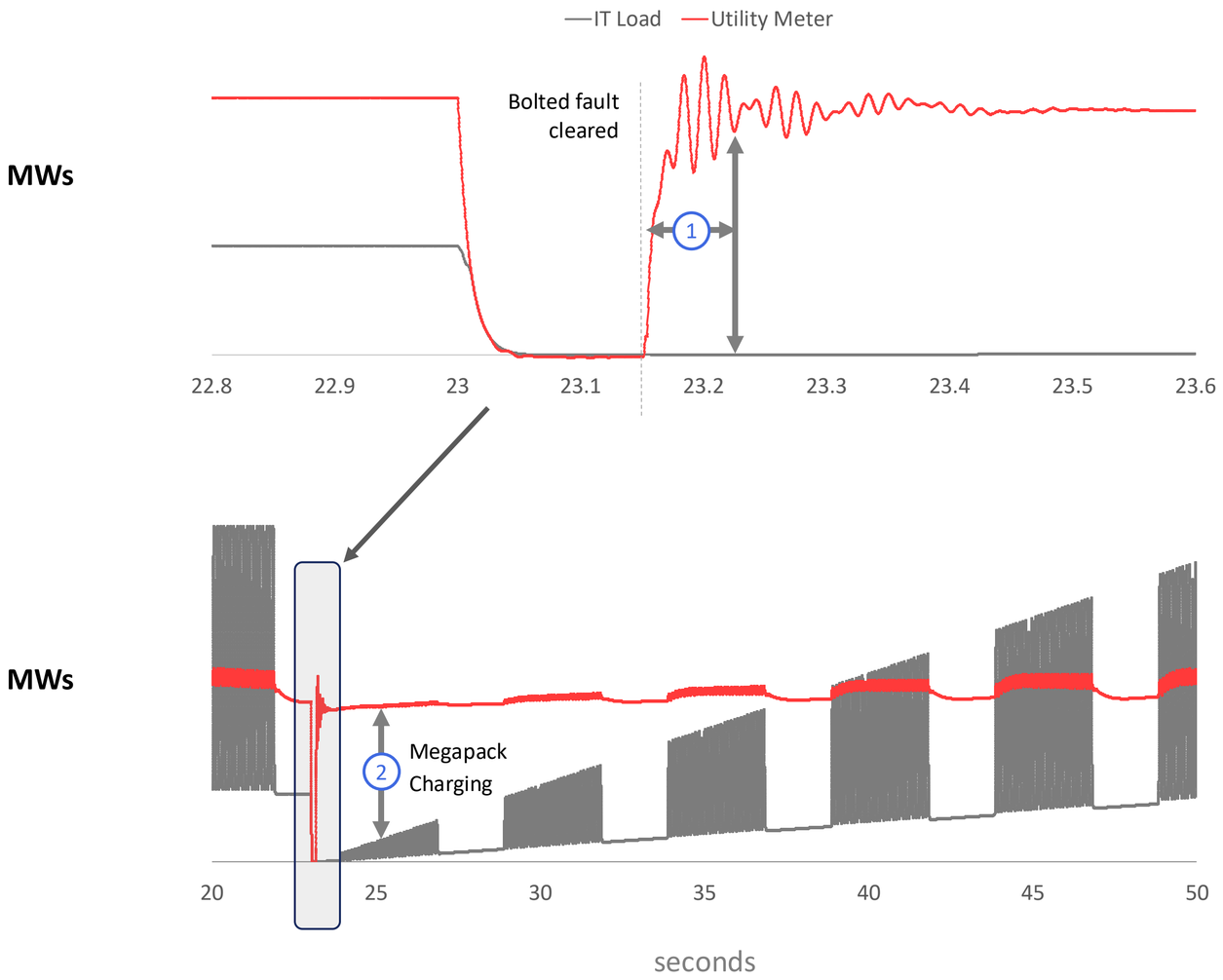
Grid Operator Perspective

- Challenging to manage load drops at this scale
- Over frequency and voltage concerns

Data Center Perspective

- UPS systems working as intended
- Protecting our expensive and reliability critical equipment from utility system faults

Solution: Megapack charging after UPS systems trip to improve LVRT behavior



Megapack can ‘mimic’ load in ~30 ms after voltage recovery

1. Power draw from grid stays the same via Megapack charging
2. Can maintain consistent utility draw as UPS / server systems transition back to grid – often phased
- Requires no change in UPS / data center setting & power configurations (other than addition of Megapack)

Assumptions / Notes

- 150ms bolted fault at POI – Voltage drops to 0pu
- Megapack system is capable of ride through IEEE2800 requirements

Challenge: Data Centers need power fast, serving them requires system upgrades

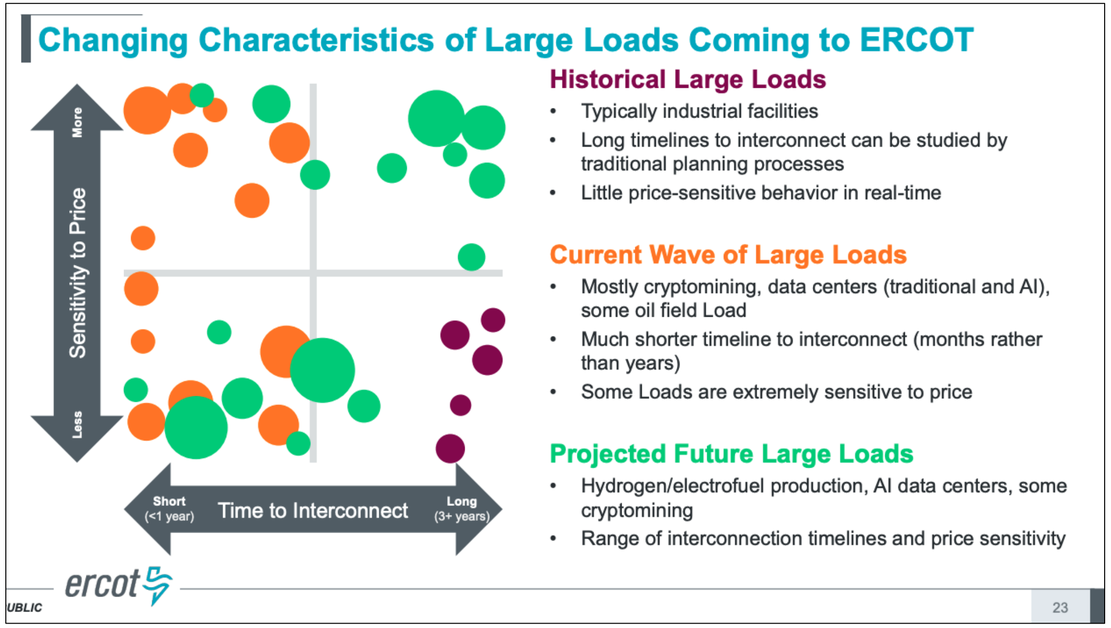
Market	Market Share by Net UPS Power	Months	Month-Year
Pittsburgh, PA	0.3%	36	May-27
Chicago, IL	7.7%	36	May-27
Houston, TX	1.7%	36	May-27
Dallas, TX	6.6%	36	May-27
Cleveland, OH	0.5%	36	May-27
NYC Metro	5.7%	42	Nov-27
San Antonio, TX	0.7%	42	Nov-27
Austin, TX	0.9%	42	Nov-27
Minneapolis, MN	0.7%	42	Nov-27
Salt Lake City, UT	1.9%	42	Nov-27
Northern Virginia	29.2%	42	Nov-27
Las Vegas, NV	1.3%	42	Nov-27
Raleigh/Durham, NC	0.3%	48	May-28
Seattle, WA	1.8%	48	May-28
Central Washington State	2.0%	48	May-28
Nashville, TN	0.3%	48	May-28
Phoenix, AZ	5.3%	60	May-29
Atlanta, GA	3.3%	72	May-30
Portland, OR	2.2%	72	May-30
Sacramento, CA	1.1%	72	May-30
Silicon Valley, CA	7.2%	72	May-30
Columbus, OH	0.8%	84	May-31

Data Centers Face Seven-Year Wait for Dominion Power Hookups

Biden Executive Order to Fast-Track AI Data Centers and Energy Infrastructure on Federal Lands

January 17, 2025

Trump plans to use emergency powers to fast-track generation co-located with AI



Data centers

- Want reliable power fast
- Load sizes are getting bigger – GW scale

Power sector

- Has multi-year lead times for expansion projects
- Supply chain crunches on key components

Load interconnection timelines have driven increased interest around off-grid microgrid systems

Solution: Megapack can help shape load to grid's needs

Load As-Is

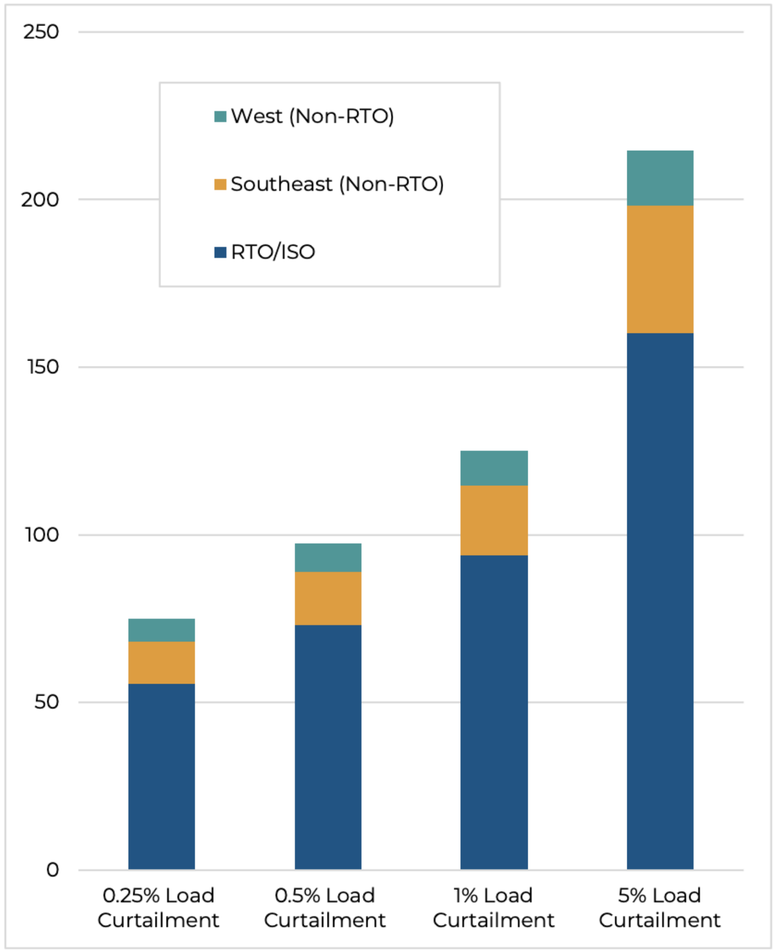
- Can not support w/ existing infrastructure
- Likely delays in energizing new load

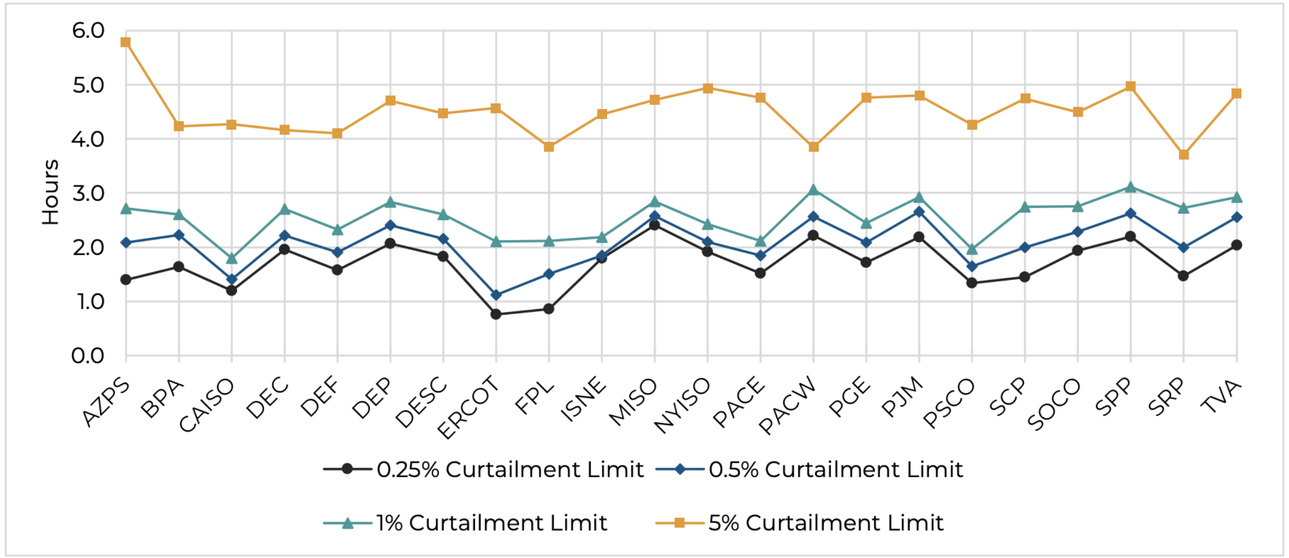
Adjusted Load (with BESS)

- Can support w/ existing infrastructure
- Shaping possible w/ 4hr BESS

How much capacity can be unlocked?

Duke study shows 100+ GWs capacity unlock possible with 2-5 hrs of load shifting





Duke Study Summary

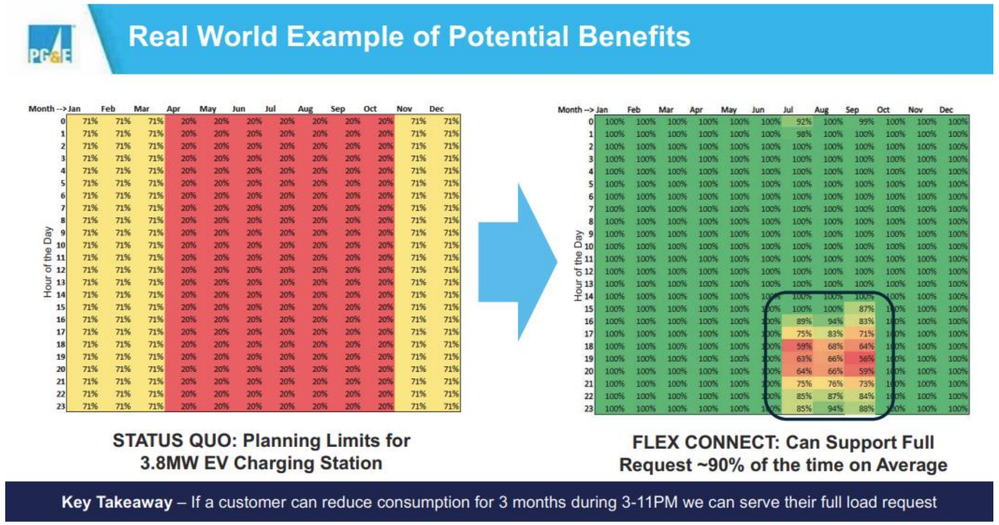
- Analyzed 22 Balancing authorities serving 95% US's peak load
- Capacity equivalent to 10% of US's peak load can be unlocked with 0.25% curtailment of new load
- Required 2-5 hr curtailment can be enabled through BESS storage on-site

Duke study ref: https://nicholasinstitute.duke.edu/sites/default/files/publications/rethinking-load-growth.pdf

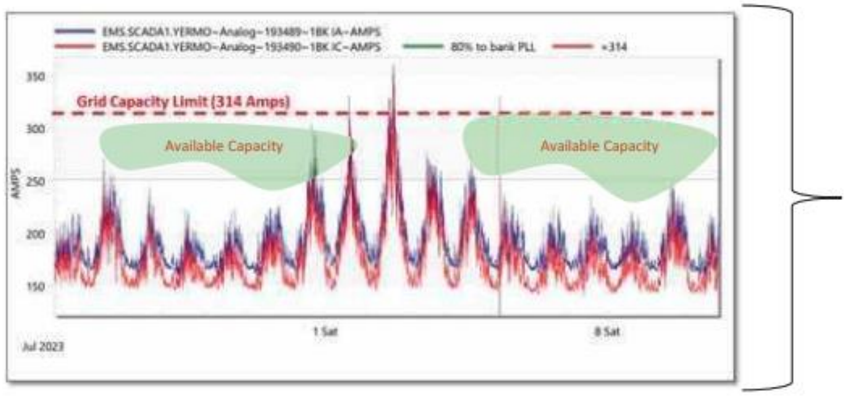
Interruptible’ or 'flex connect' load interconnection programs starting to emerge

Megapack can manage constraints placed on load to make no/low impact while accelerating full load energization

PG&E Example



SCE LCMS Example



An LCMS can be used to allow the flexible load (e.g., charging station) to use more capacity outside the peak period

Grid Operator: What is your choice?

- Connect in 5 yrs when upgrades are done
- Connect now, turn down load [5]% of the time
  - Megapack can make ‘no impact’ to facility

Some ‘formal’ programs like this include

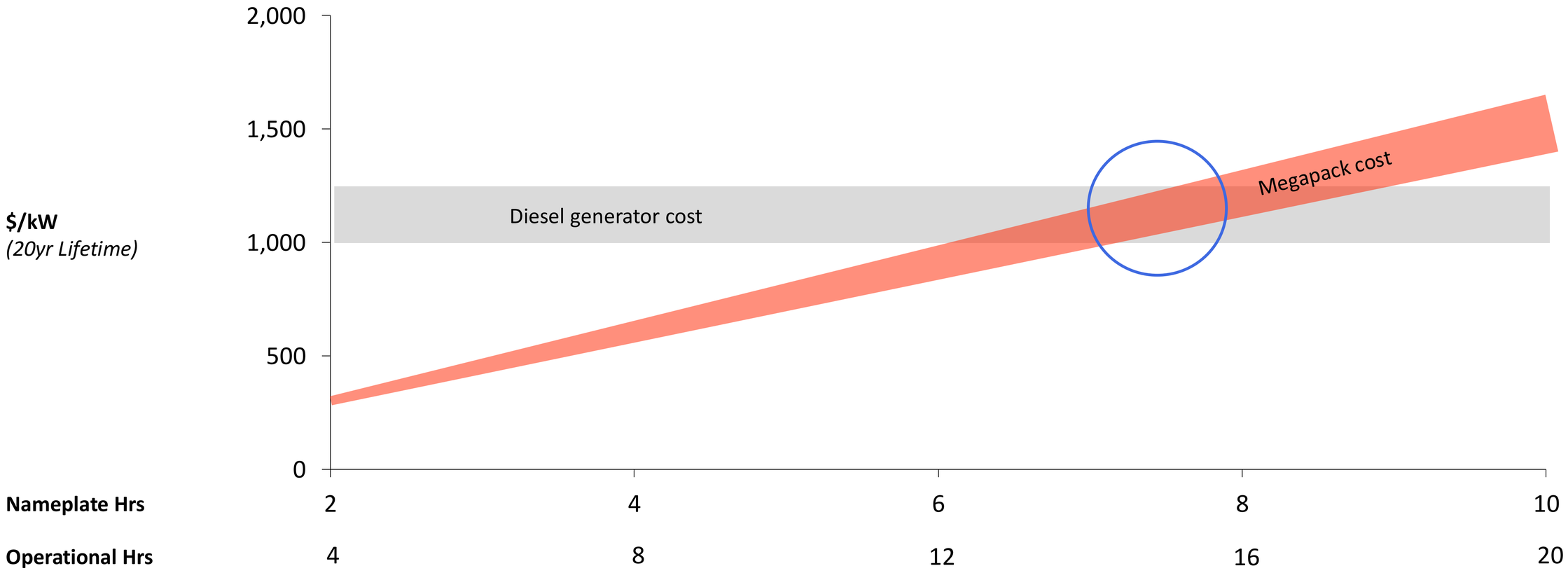
- PG&E – ‘FlexConnect’
- SCE – LCMS pilot
- Black Hills ‘Blockchain Interruptible Service’
- National Grid UK – Flexible Connections

Tesla Experience

- Supercharger + Megapack in PG&E FlexConnect
- Semi Charging + Megapack in PG&E FlexConnect

Back up power: Megapack cost competitive vs diesel generators for ~16 hours of back up

Fewer hassles (air permits, testing, diesel swaps) without the emissions



Megapack operational hrs assumes 50% nameplate loading

Megapack cost assumes

- 50% ITC (30% base, +10% 'domestic adder', +10% 'Energy Community' adder that many major metros qualify for) netted from CapEx expense – Please consult your tax adviser on all tax related matters.
- Nominal installation expense which may vary dependent on site conditions etc
- Includes nominal O&M cost for 20 years, per standard services agreement.

Generator cost assumes

- Capex of $800-1,000/kW installed
- Maintenance cost at 2.5% of capex annually for cost of service agreement & fuel swaps

Applications & considerations of various solutions

	AI Load Smoothing	LVRT support	Flexible grid connection	Lifetime (with smoothing)	Space (Acres/100 MW DC)
5 Min Battery (UPS)	Maybe	Maybe Objective Conflict	No Duration Limited	~1 yr Cycling Limited	N/A Existing Equipment
On-site generation (Diesel Generator)	No	No	Maybe Air permit limits use	N/A Can't load smooth	N/A Existing Equipment
Capacitors (E-Statcom)	Partially (Fast = yes, Slow = unlikely)	No Duration Limited	No Duration Limited	20 yrs	~0.5
2H BESS (Megapack)	Yes	Yes	Yes	20 yrs	~0.5

Megapacks at Large Loads

Tesla Gigafactory Texas

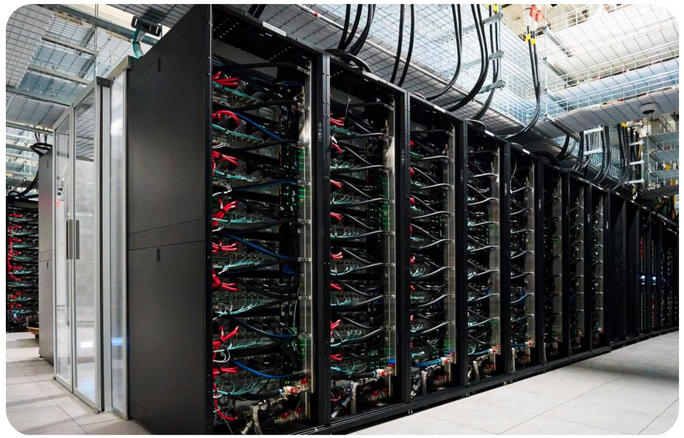
xAI Colossus

Megapack

Tesla Gigafactory Texas

Large Load & Megapack Overview

Overall facility



Gigafactory Texas Megapack Infrastructure

Facility is a large load 2-in-1 located in Austin Texas

- Large manufacturing plant
  (largest building in world - 10M sqft)
- 130 MW data center

Have 2 Megapack installations at the facility

1. Data center Megapack system 130 MW/260 MWh
   - Installed “Behind the Meter”
   - Back up power use case

2. ERCOT participating system – 125 MW/250 MWh
   - Installed “Front of the Meter”
   - Can provide back up power in a grid outage with unique configuration (ERCOT NPRR 1100)

Also have 15 MW rooftop solar system – Spells TESLA

xAI Colossus

Large Load & Megapack Overview

xAI’s Collossus

- 200k GPU cluster, ~250 MWs
- AI load smoothing & demand response use cases

Questions?

Please reach out to IndustrialContent@tesla.com with inquiries following today