From burden to backbone: How Data Centers become good grid citizens

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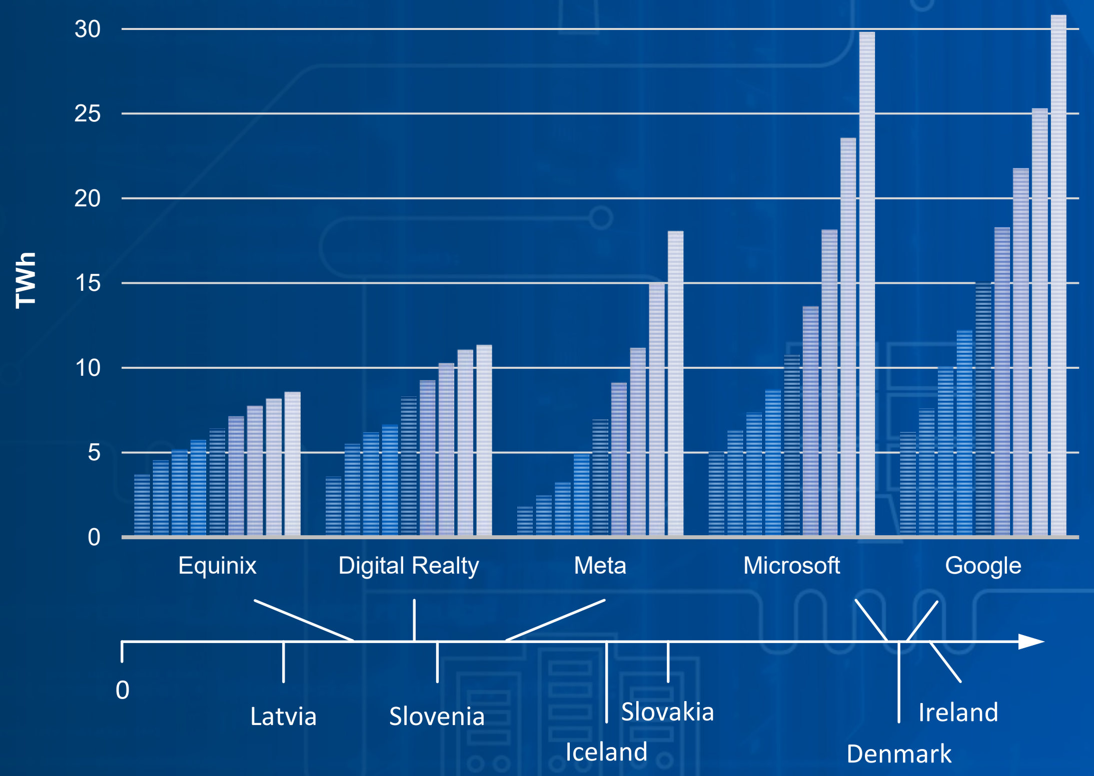
New challenges for electricity grid

Selected DC operator energy growth 2016 - 2024



Source: Published sustainability reports

Data centre share of overall power demand is increasing, and having a bigger role in energy system

High concentration of data centres and demand in key locations

Potential impact to grid power quality, stability and reliability is increasing and getting significant

System operators have identified issues relating to consumers with large electronic loads

New technical regulation needed to ensure planned data centre capacity can be added to grid

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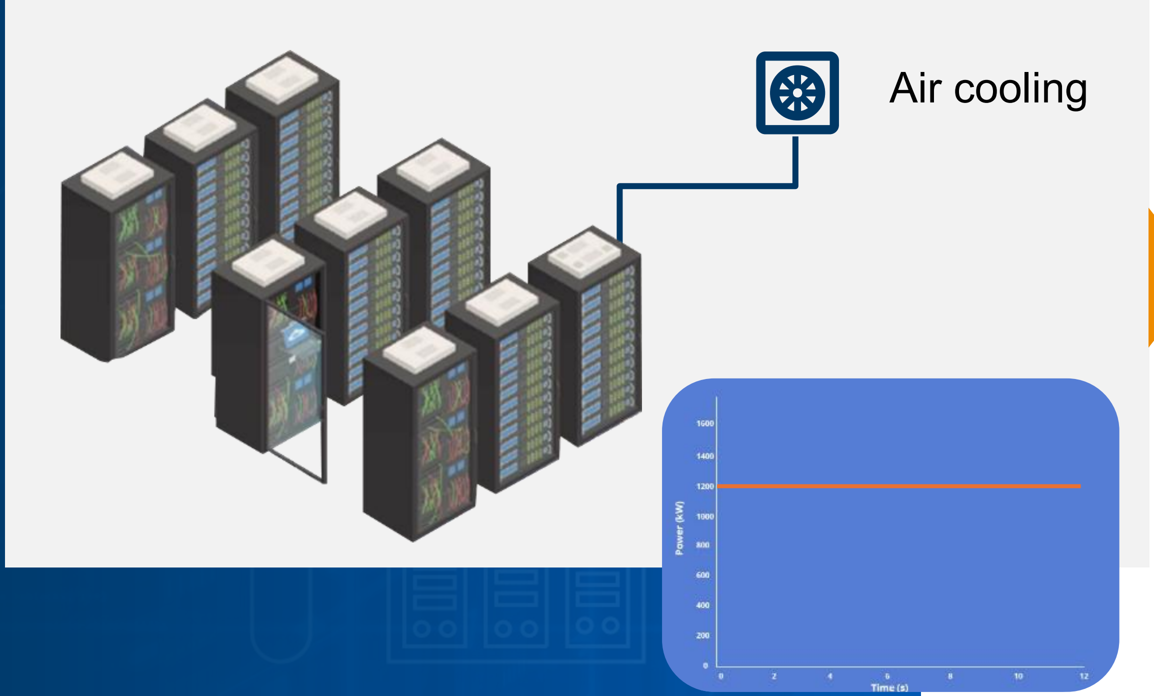
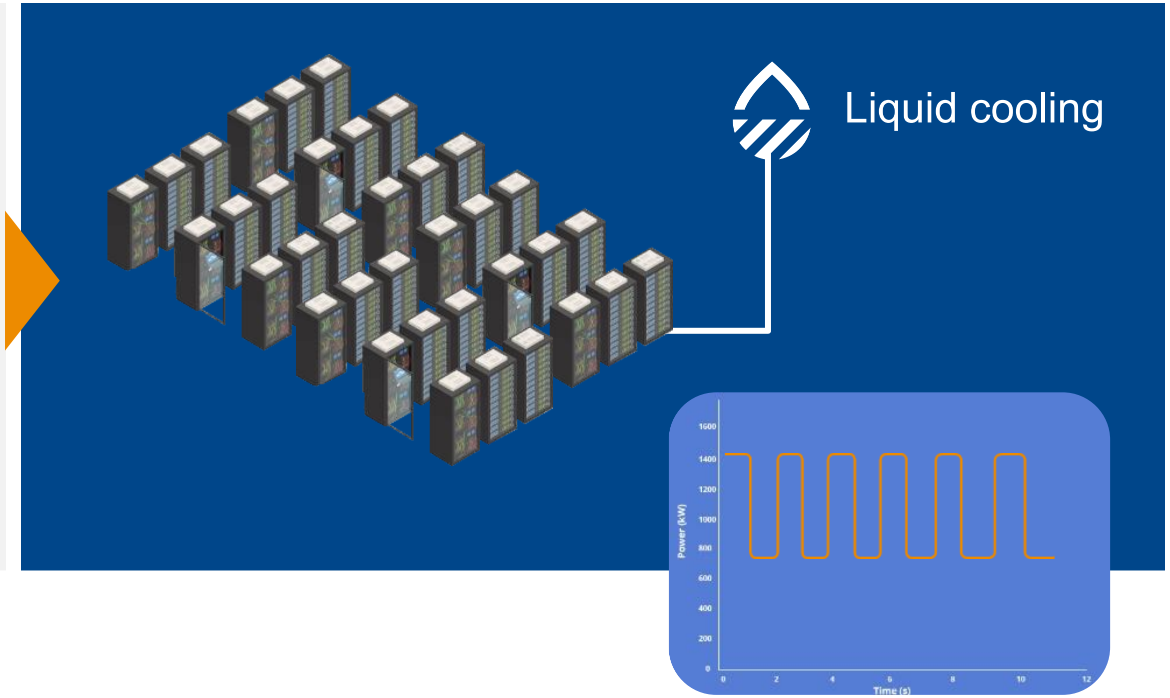
AI is changing the characteristics of data centres

Scale **Cooling** **Load**

~10MW Traditional data centre



>100MW AI data centre campus



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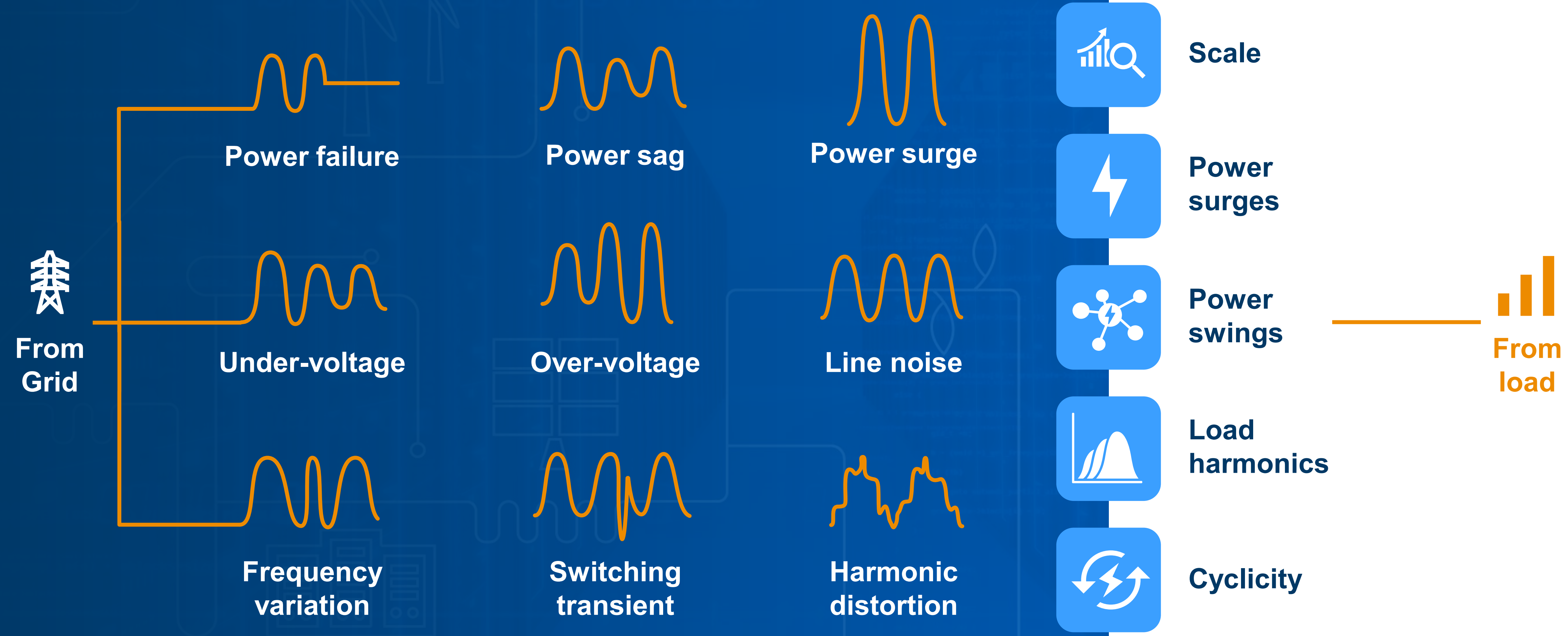
…resulting in five new power problems



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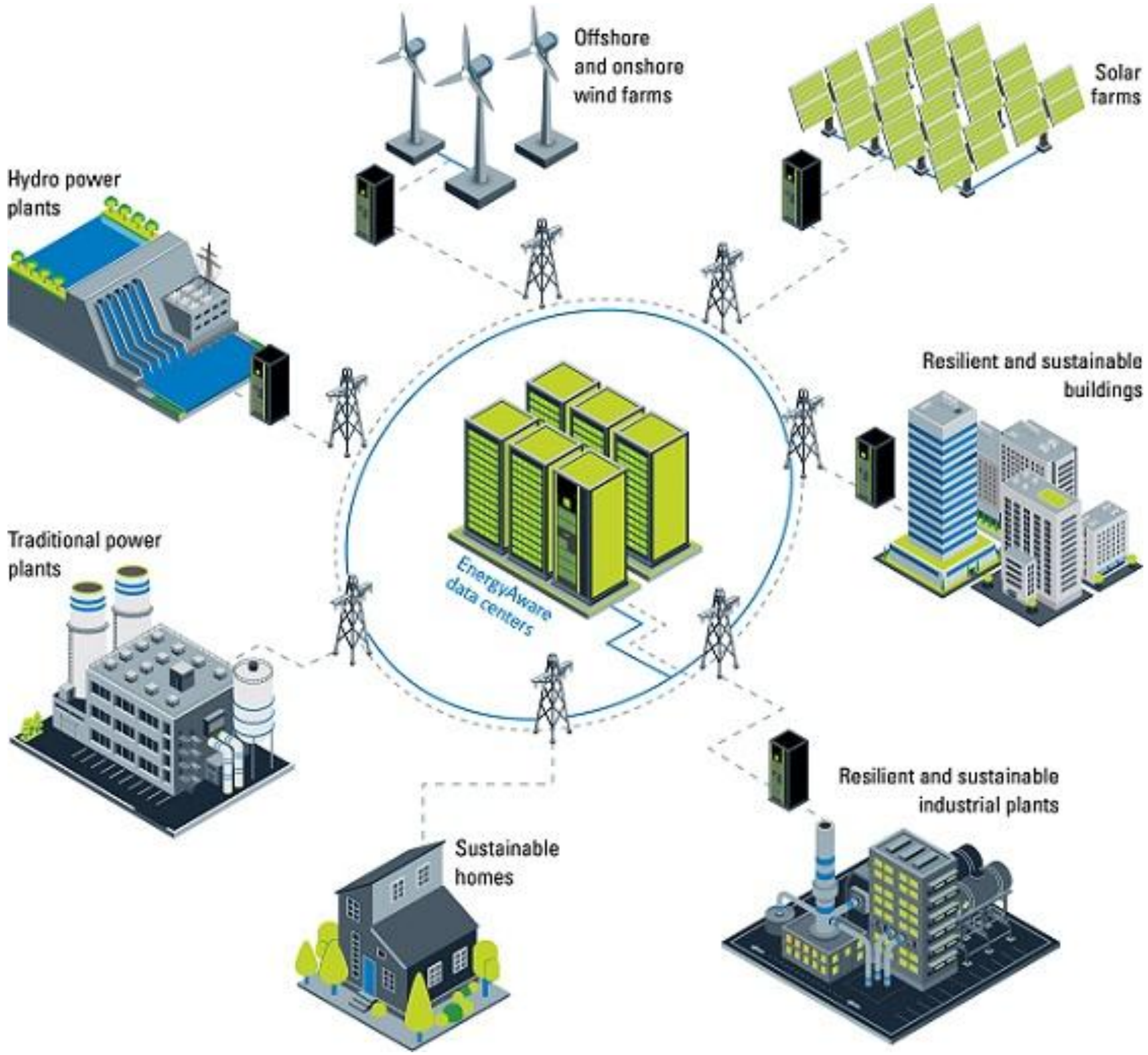
AI load variation challenges for power system

- On-site (back-up) power generation compatibility to fast repeating load swings
- Voltage stability and interaction with other loads within data centre
- Flicker effect and other power quality issues for electricity grid and other consumers
- Voltage and frequency stability of bulk power system (BPS) with largest load variations
- Phase jump / shift and local RoCoF and frequency variations
- Forced, interarea and torsional oscillations and unwanted interaction with other assets in the grid



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New grid connection requirements for large electronic loads

Multiple system operators around the globe have identified issues relating to large loads with power electronics and have published or are preparing new regulation

Many near miss incidents reported in locations with high number of data centres*, such as Virginia and Texas

New requirements to be introduced, such as **Fault Ride Through (FRT)** and **Post Fault Active Power Recovery (PFAPR)**

Higher focus on impact to power quality and system stability during permitting process and more stringent limits for power factor, harmonics, flickering etc.

Simulation models of converter-based loads are required during permitting process, such as:

- PSCAD (EMT)
- DigSilent PowerFactory
- PSS®E

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* https://www.reuters.com/technology/big-techs-data-center-boom-poses-new-risk-us-grid-operators-2025-03-19/

Fault Ride-Through (FRT)

For generating side, a requirement to be a near fault tolerant exists today:

- Avoid disconnection of generation capacity from the grid during short momentary voltage interruptions i.e. Faults
- Generating assets remain connected during under voltage and feed constant current to sustain voltage (UVRT)
- After fault generators quickly restore their output power to pre-fault level (PFAPR)

- There has not been such a requirement for large loads and demand side
- Especially power electronic converters and other electronic loads are problematic as they typically tolerate limited voltage variations and interruptions, and turn off once limits are exceeded
- Loads do not quickly restore the demand after system voltage recovers, causing a significant system imbalance when occurring in large enough capacity

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New grid connection requirements landscape

- Unprecedented growth of demand in many utilities driven by data centres
- Data centres seen as matter of **national security** topic
- **Complexity of regulation**, varies from utility to another and state to state
- Some **system operators** planning and implementing **new requirements**
- NERC working on interconnection standards for large electronic loads

- EU ambition to **triple** number of **data centres by 2030** (digital strategy)
- Individual countries (TSO) planning and implementing new requirements
- Work **started to create the technical requirements** (recomm.) for DC as part of new NC for DC (DCC2.0), lead by ENTSO-E and EUDCA
- Takes several years to become a harmonized requirement (directive)

- **AU data centre** to grow fourfold within the next decade to roughly consume about **11% of national electricity consumption** (CEFC)
- Weakening grid due to retirement of traditional coal and gas power plants.
- AEMO / AEMC set to release a **disturbance ride-through standards** for IBL by mid-2026.

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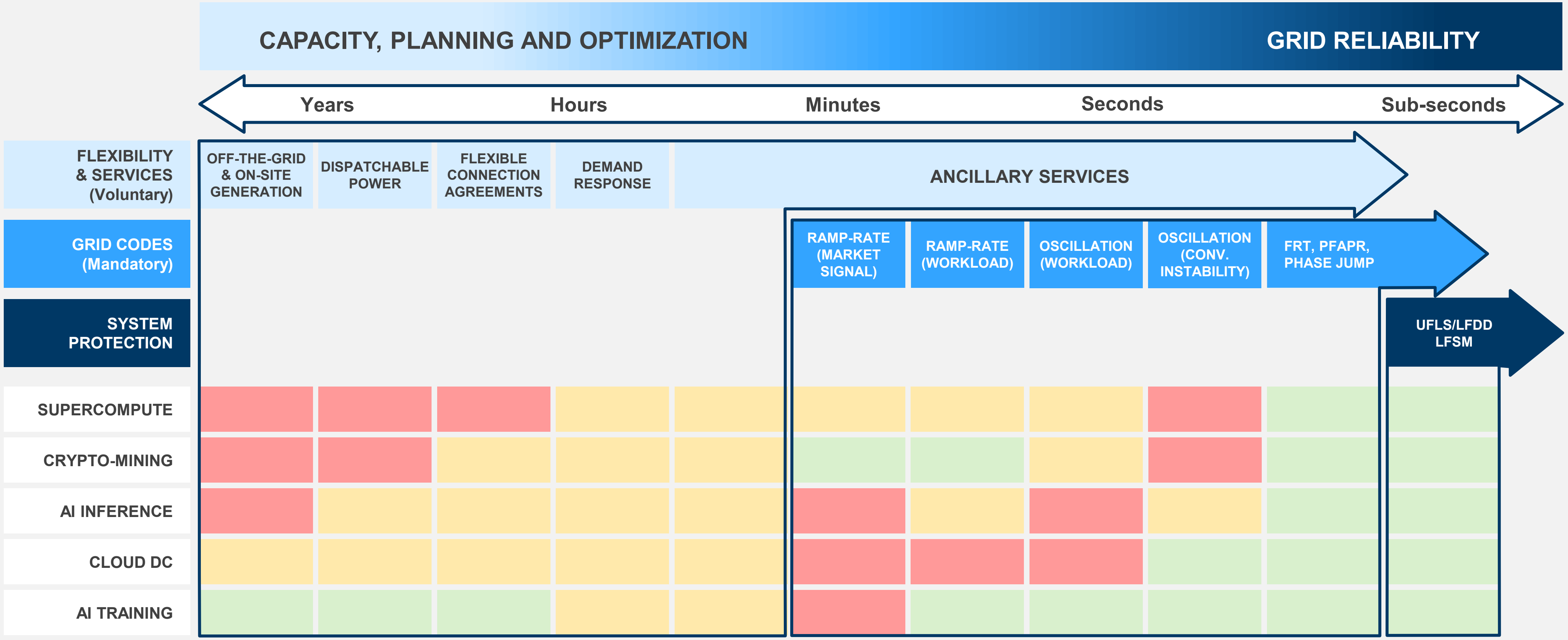
Data centres, flexibility and grid codes



Applicability: YES MAYBE N/A

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Grid-interactive UPS

Energy management, grid services and flexibility bringing additional revenue streams and savings for asset owner

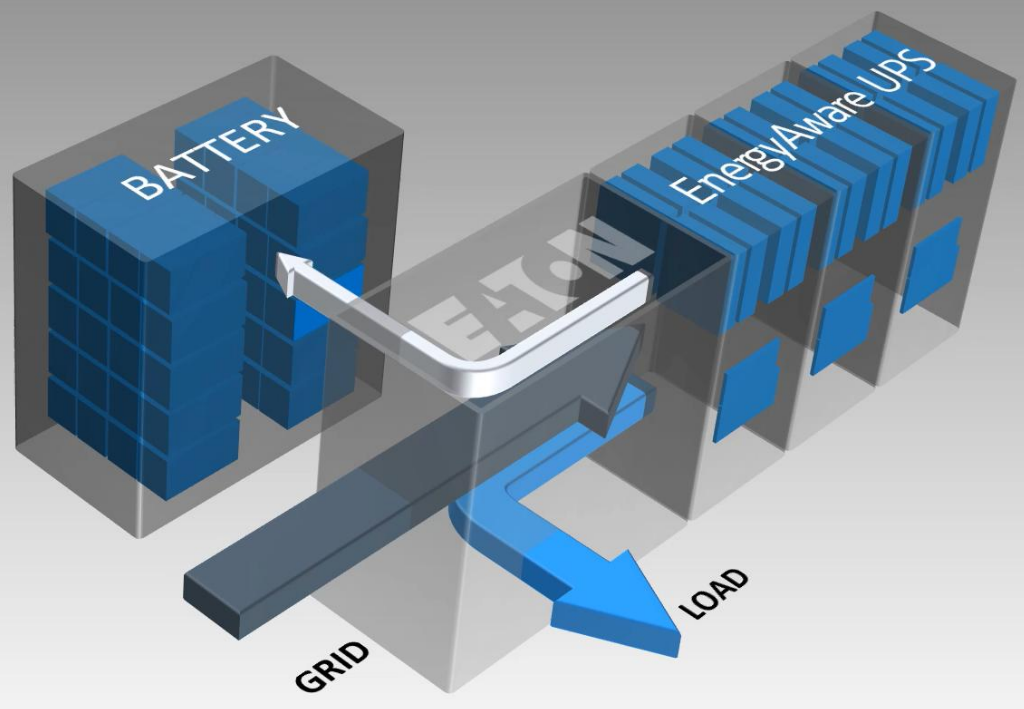
Support grid to allow higher penetration of non-synchronous generation and avoid curtailment of renewable energy

Support grid and on-site power generation to manage load transients and ramping

Filter harmonics, power factor and load oscillations to eliminate power quality issues

Comply with new grid connection requirements for data centres such as FRT, PFAPR, UFLS

Eaton's EnergyAware UPS



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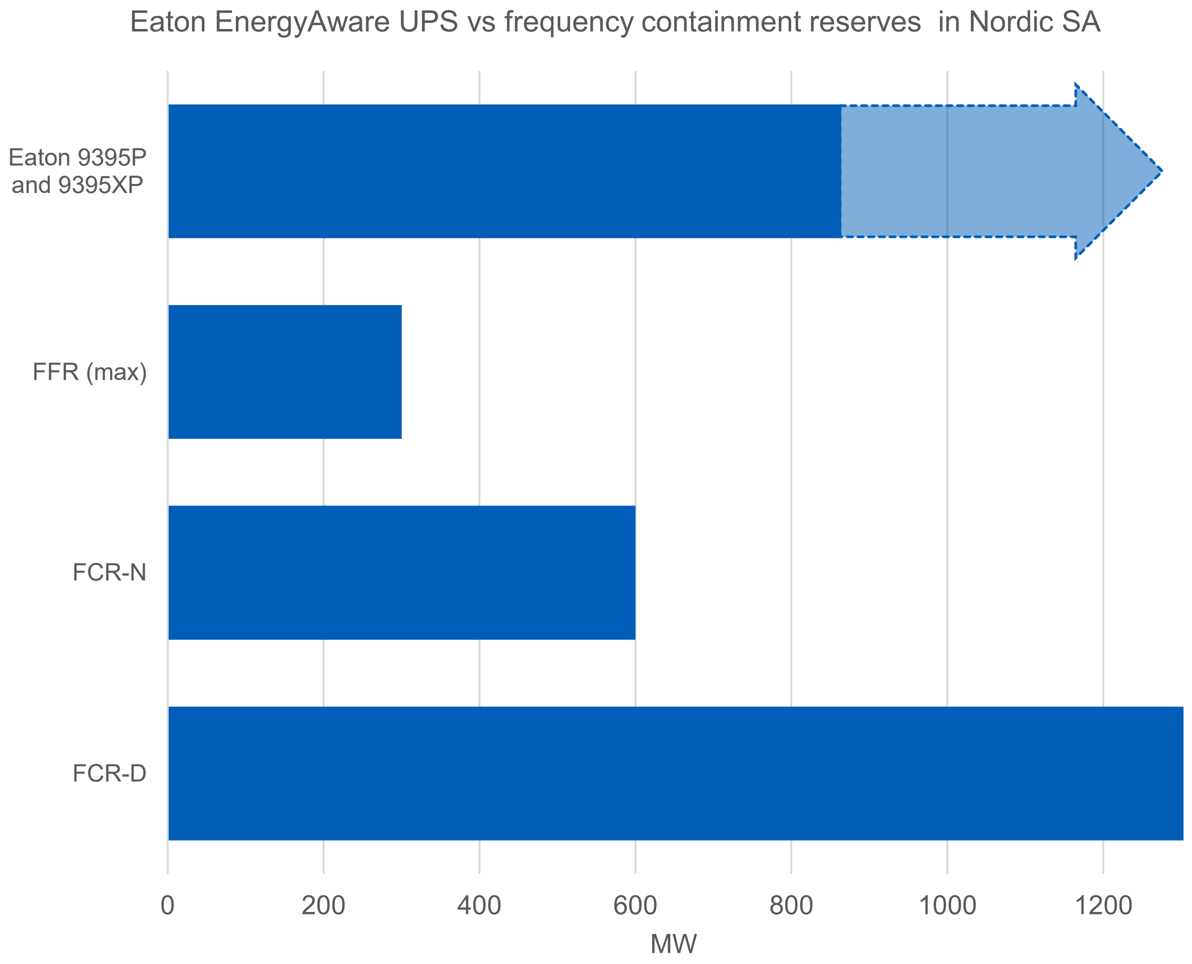
UPS in ancillary services



https://www.fingrid.fi/sahkomarkkinat/reservit/sahkojarjestelman-reservit/#reservivelvoitteet

- Data centre power capacities to be compared against reserves volumes and reference incident, not size of the system
- Data centres potential to provide grid services is therefore significant
- Some grid services may require additional investment while others like FFR are low hanging fruits
- Eaton UPS capability to provide grid services has been proven in pilots and real-life use cases

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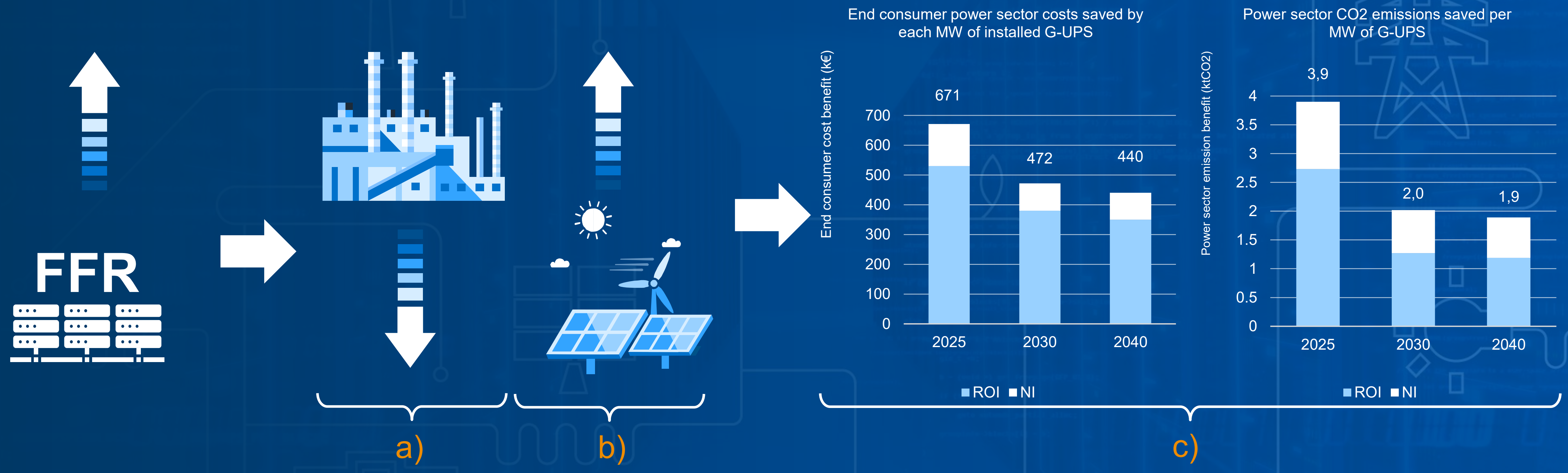
Grid-interactive UPS socioeconomic impact

Fast frequency response allows to **a)** reduce inertia floor and retirement of traditional generation and **b)** higher penetration of renewable energy and reduces curtailment that **c)** reduces emissions and operating cost of the system



100 x greater impact to reduction of emissions than 1% improvement in UPS efficiency

1) Baringa: Irish decarbonisation and consumer benefits of Grid-Interactive UPS https://www.baringa.com/contentassets/8771b5d7c2ee4f1598d746b5ceafbcd3/baringa_irish_decarbonisation_g-ups_study_report_v4_0.pdf
2) EirGrid and SONI: Shaping our electricity future, 2021. http://www.eirgridgroup.com/site-files/library/EirGrid/Full-Technical-Report-on-Shaping-Our-Electricity-Future.pdf
3) System Services Future Arrangements Scoping Paper SEM-20-044, A Submission by EirGrid plc. & SONI Ltd. 2020. https://www.semcommittee.com/sites/semc/files/media-files/SEM-20-074a%20-%20EirGrid%20and%20SONI%20Response%20to%20SEM-20-044.pdf

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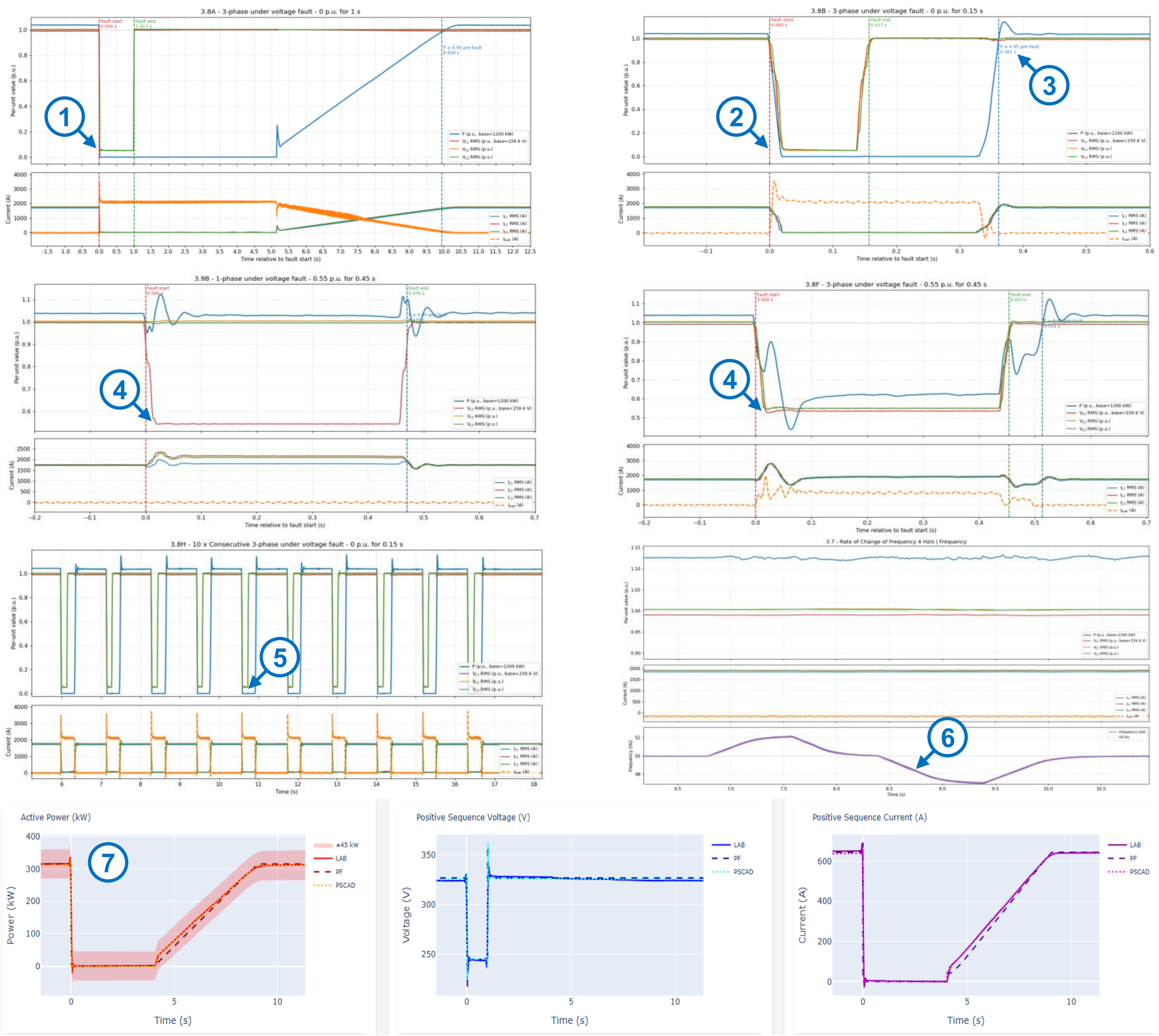
Grid-friendly UPS

- UPS to differentiate between (1) real mains outage and (2) short interruptions
- Perform (3) PFAPR to restore demand and maintain system balance after a fault
- Extend (4) input voltage operating range down to 0.5 pu to reduce blast radius and tolerate unsymmetrical faults
- Tolerate (5) multiple faults and (6) high RoCoF (up to 4 Hz/s)
- Stable operation in grids with low system strength (PSCAD for system studies)
- Simulation models such as (7) PSCAD, PSS®E, PowerFactory
- Provide data on equipment; harmonics, interharmonics, harmonic impedances, flicker



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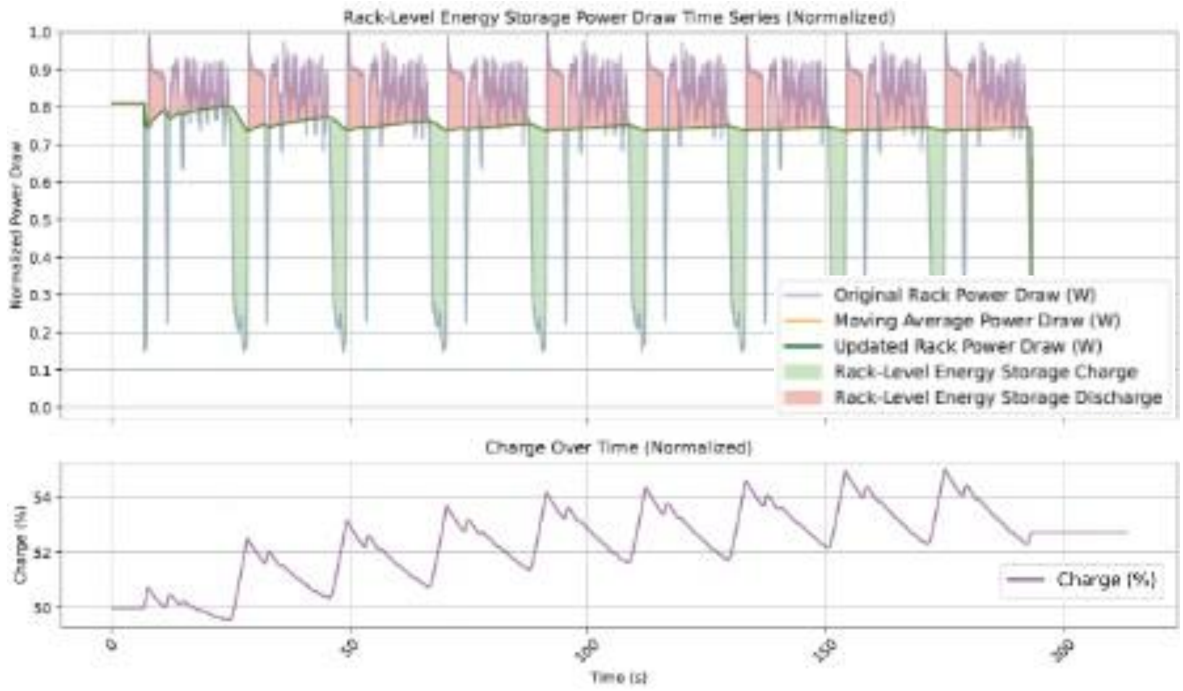
AI load mitigation within IT

- Some load smoothing can be done with new GPUs
- Minimum Power Floor (MPF) uses “dummy operations” during idle to eliminate valleys and to ramp-down load
- Additional filtering at PSU or rack level by leveraging energy storage devices (supercaps)
- Above reduces transients for upstream power infrastructure, but additional filtering can be needed to limit load ramp-rate for grid and eliminate oscillations
- Vast quantity of older / other xPUs shipped and yet to be deployed (Nvidia shipped >6 million GPUs during 2025 alone*)

*) https://www.cnbc.com/2025/11/21/nvidia-gpus-google-tpus-aws-trainium-comparing-the-top-ai-chips.html#:~:text=Once%20used%20primarily%20for%20gaming,GPUs%20over%20the%20past%20year.



Solution	Reliability	Performance	Energy	Cost	Ability to meet tightest spec	Dependency on the developer	Lifetime
Software-only mitigation	Medium	Medium	High	Medium	High	High	High
GPU power smoothing	High	Medium	High	Low	Medium	Medium	Medium
Rack-level energy storage	High	High	Low	High	High	Low	High

TABLE I

SUMMARY OF VARIOUS PROPOSED SOLUTIONS. FOR ENERGY, COST, AND DEPENDENCY ON THE DEVELOPER, LOWER IS BETTER.

Choukse, E., et al. Power Stabilization for AI Training Datacenters. https://arxiv.org/abs/2508.14318

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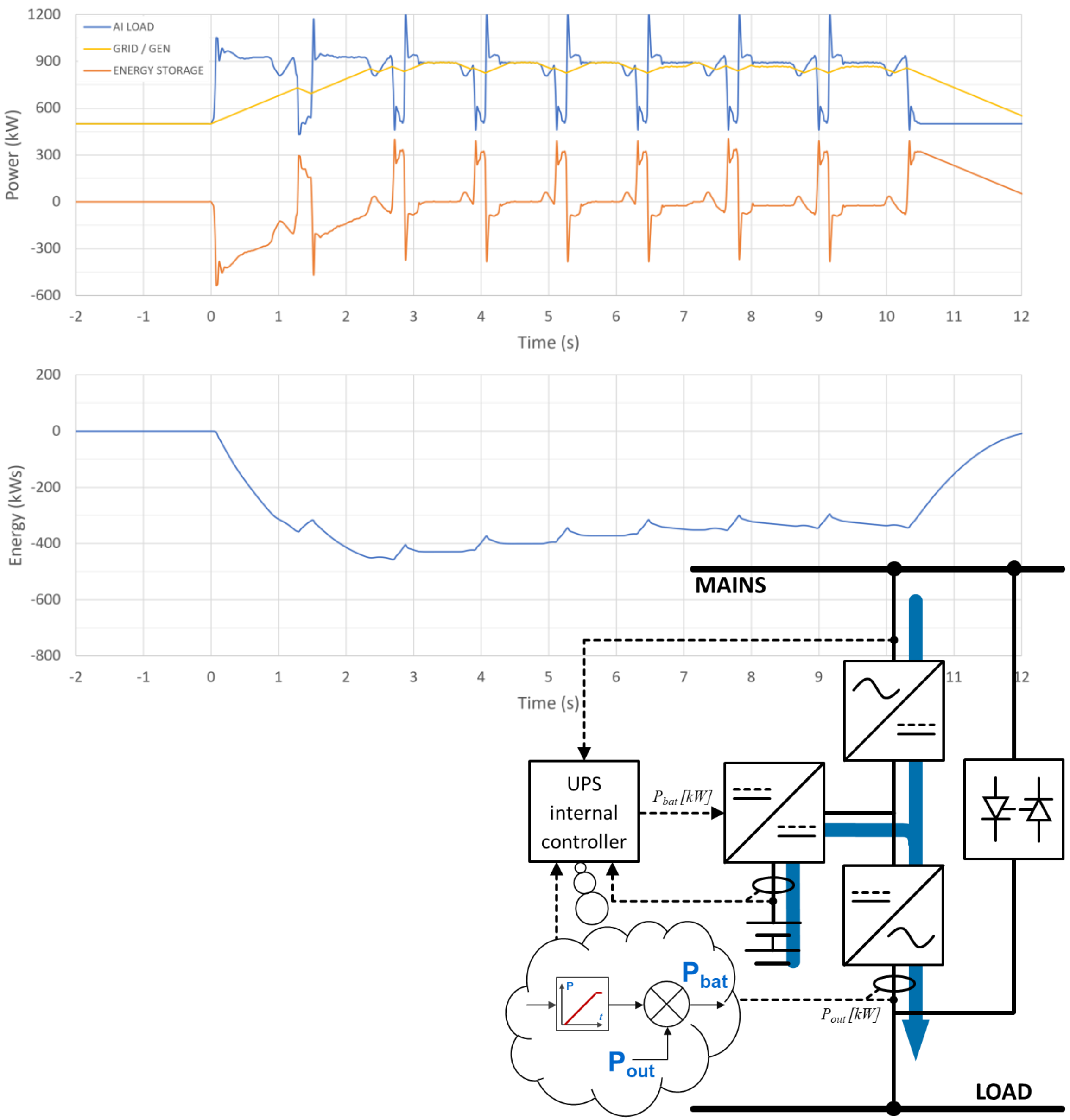
UPS for AI load mitigation

- Highly cyclic load:
  - From thousand to millions of discharge and charging cycles
  - Need supercapacitors or next generation lithium batteries optimized for application
- Supercapacitors:
  - High number of cycles
  - Limited energy and very short run-time and high cost
- Next generation lithium:
  - With correct sizing can support AI load smoothening to manage fast variations and demand ramp rates
  - Provides enough back-up time
  - Lowest cost



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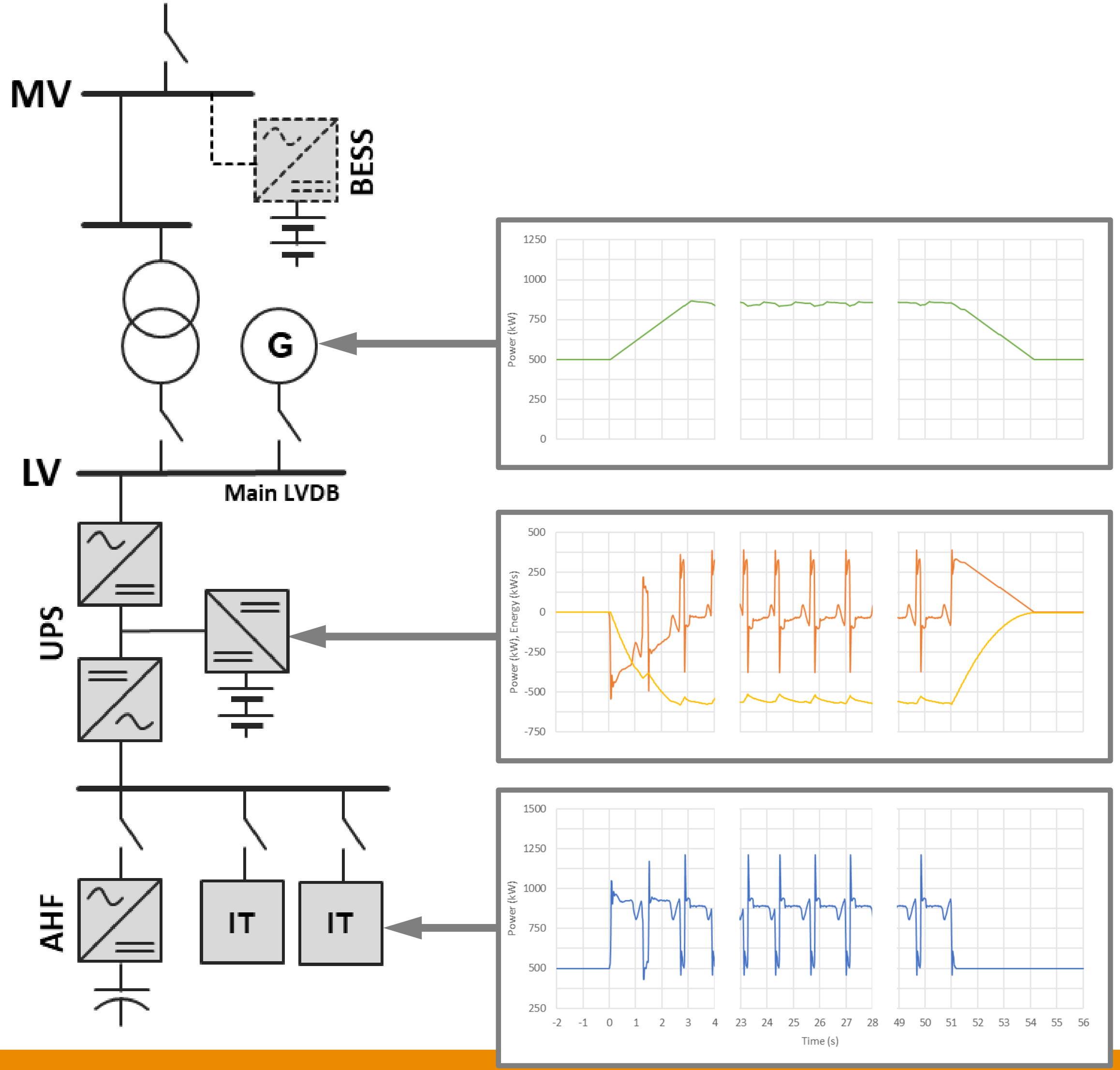
AI load filtering

- Fast load transient filtered close to or within IT load with SW, GPU, rack PSU, or PDU level
  - Software / GPU based solutions
    or
  - HW solutions based on super- or hybrid-capacitors
- Further filtering, as required, with a LV UPS or AF
  - Resulting load variations within acceptable limits for upstream power infrastructure such as transformers and generators
- Additional control of active power to manage ramp-rate (MW / min) limits for grid connection
  - LV UPS or (MV) BESS
  - Ramping time from tens of seconds to few minutes



***) 50 MW AI load and 50 MW/min ramp limit for a data center:**
- **BESS sizing 50 MW / 50 MWh with associated MV distribution, installation, service etc. (>20 MUSD)**
- **50 000 kW * 60 s / 3600 / 2 = 417 kWh overall energy for ramp control or 8.3 kWh per each MW of UPS capacity (<1 MUSD)**

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Data centre as a good grid citizen

Efficiently recycles waste heat

to provide for example district heating to decarbonize heat production and networks

Provides flexibility and services

for electricity grid to enable higher penetration of renewable energy sources and to reduce system emissions and balancing cost

Supports electricity grid

and helps to manage contingency events to improve grid reliability

Does not negatively impact electricity grid power

quality, stability and reliability

A good "grid citizen" is one that doesn't impact power quality, abides by regulatory requirements and gives back to the community

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https://www.eaton.com/us/en-us/markets/data-centers/good-grid-citizen.html