Multiscale Power-Grid Intelligence for AI Data Centres

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Overview

Background

Trends and Inefficiencies

Our Solution

- Broad picture
- Technical capability
- Economic incentive

Conclusions

Background

- AI data centre power demand is exploding
  - 2024: 415 TWh (≈1.5% of global electricity demand, by IEA)
  - 2035: up to 1,700 TWh (≈6% of global electricity demand, by IEA)
- AI load is uniquely challenging
  - Highly concentrated (100 MW → multi-GW scale)
  - Large transient variations (training starts/stops, backup switchovers)
- Grid connection is the bottleneck
  - Grid connection times: Europe avg. 4 years; UK/Ireland 7–10 years; U.S. 4–7 years
  - Transmission infrastructure build time: 5–15 years

Current Defection Trend and Inefficiencies

- **Grid defection trend**: by 2030, 27% of data centres may rely mainly on on-site gas generation
- However, this defection:
  - Loses grid advantages such as economies of scale in generation and shared reserve capacity (redundancy)
  - Conflicts with the net-zero target


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UK's first major AI data centre on collision course with net zero

The developments will add to fears that the government's push to make the UK a leader in AI will fly in the face of its attempts to hit climate targets

The planned Buckinghamshire SDC M40 data centre campus (£2bn):

- 300 MW hyperscale data centre
- 270–350 MW of on-site gas turbines
- SDC M40 alone would take up 10%–15% of Great Britain's implied "gas budget" for the UK Clean Power 2030 target.

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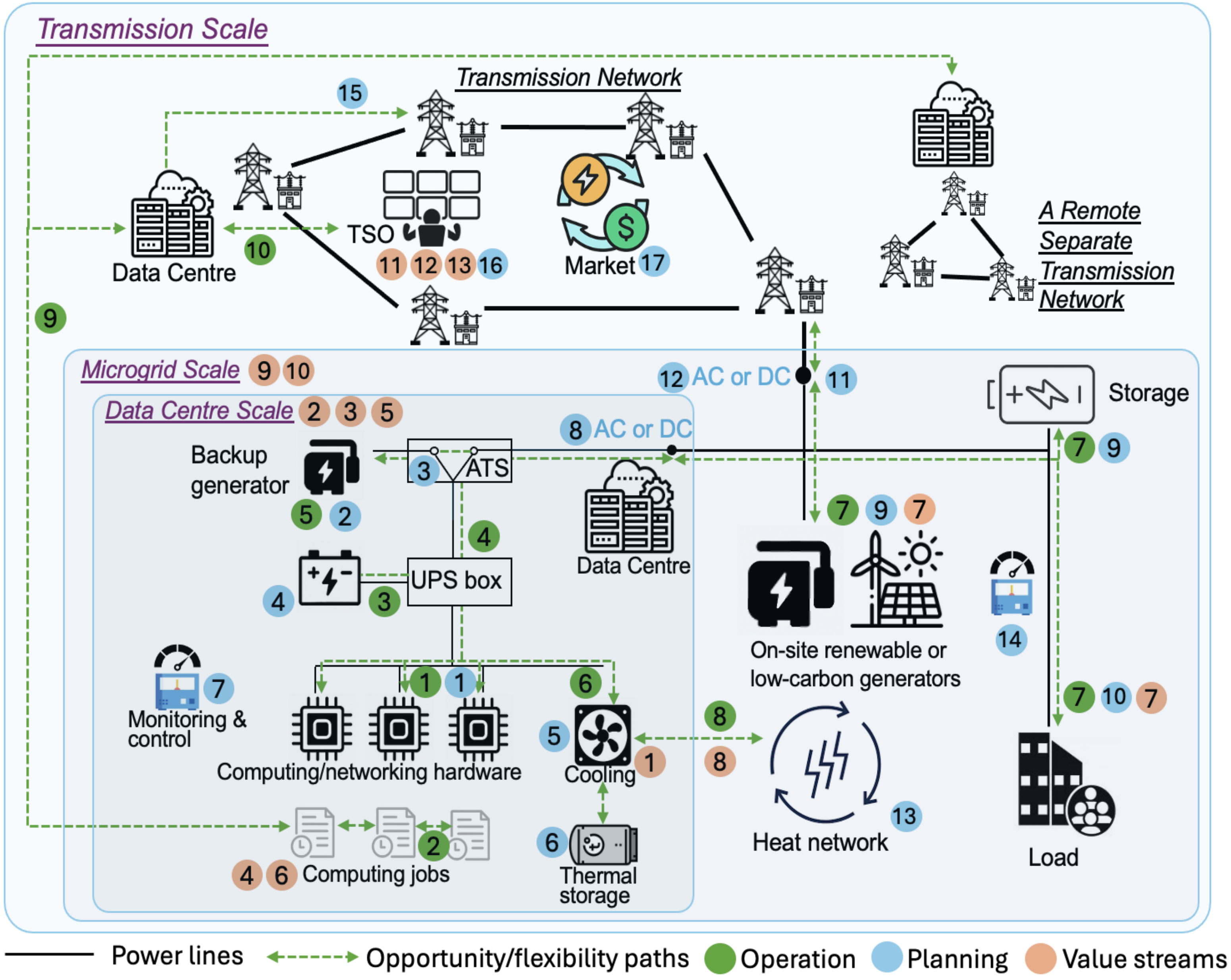
Our solution: *AI data centres can become "**grid-intelligent**" by providing valuable grid services in exchange for faster grid access and additional revenue, while keeping the impact on computing performance minimal and acceptable.*

The Bigger Picture: Multiscale Grid Intelligence

- Spatial scales: from rack-level distribution to national transmission
- Temporal scales: from second-to-second frequency regulation to years-ahead grid planning
- Sources of flexibility:
  - Cooling systems
  - Computing infrastructure
  - Backup generators and UPS
  - Microgrid generation and storage



Data Centre-Scale Grid Intelligence

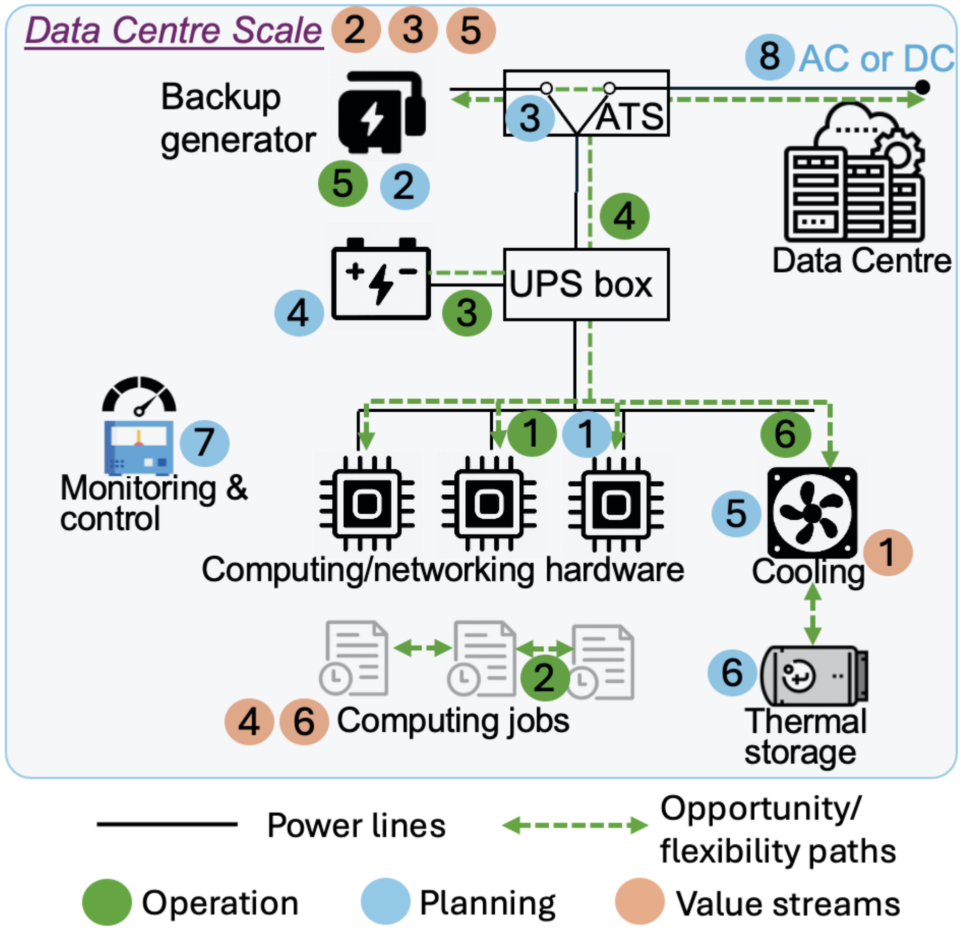
Opportunities for grid intelligence:

Operation:

1. CPU/GPU dynamic power capping
2. Job scheduling
3. UPS battery control
4. Inverter reactive power control
5. Backup generator control
6. Cooling system control

Planning:

1. ICT hardware selection and sizing
2. Backup generation selection
3. Backup generation export path
4. UPS selection and sizing
5. Cooling system design
6. Thermal storage
7. Monitoring and control
8. AC vs. DC distribution



Value streams:

1. Water use reduction
2. Energy efficiency
3. Energy cost reduction
4. Quality of service
5. Carbon emissions reduction
6. Reliability improvement

Microgrid-Scale Grid Intelligence

Opportunities for grid intelligence:

Operation:

7 Microgrid generation, storage & flexible demand control

8 Waste heat network control

Planning:

9 Primary generation & storage

10 Microgrid loads

11 Grid connection sizing

12 Microgrid architecture design

13 Waste heat network

14 Monitoring & control systems

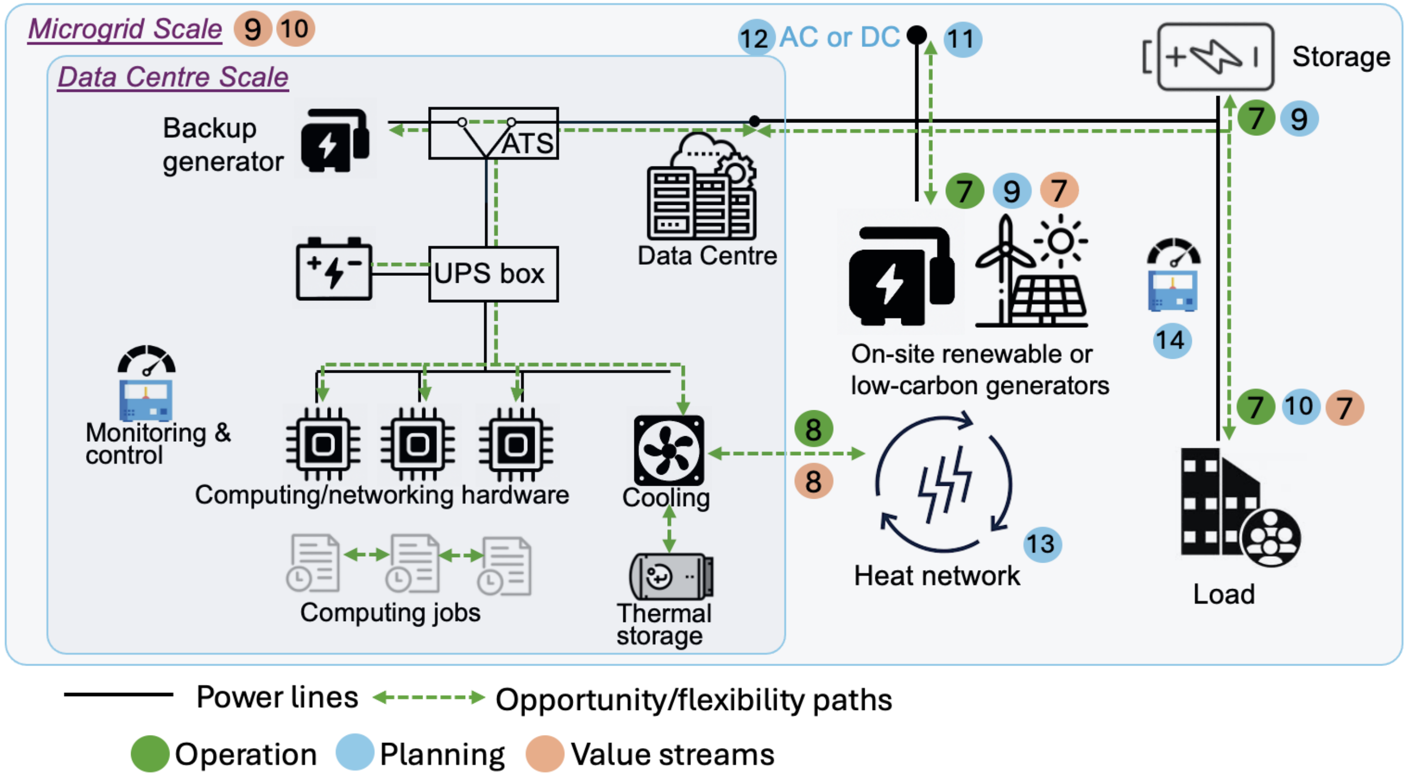
Value streams:

7 Anchor load for renewables and electrification

8 Waste heat provision

9 Grid connection speed and cost improvement

10 Land use reduction



Transmission-Scale Grid Intelligence

Opportunities for grid intelligence:

Operation:

9 Inter-data centre job routing

10 Data centre-aware grid dispatch

Planning:

15 Grid-aware data centre siting

16 Strategic, data-centre-aware power-grid planning

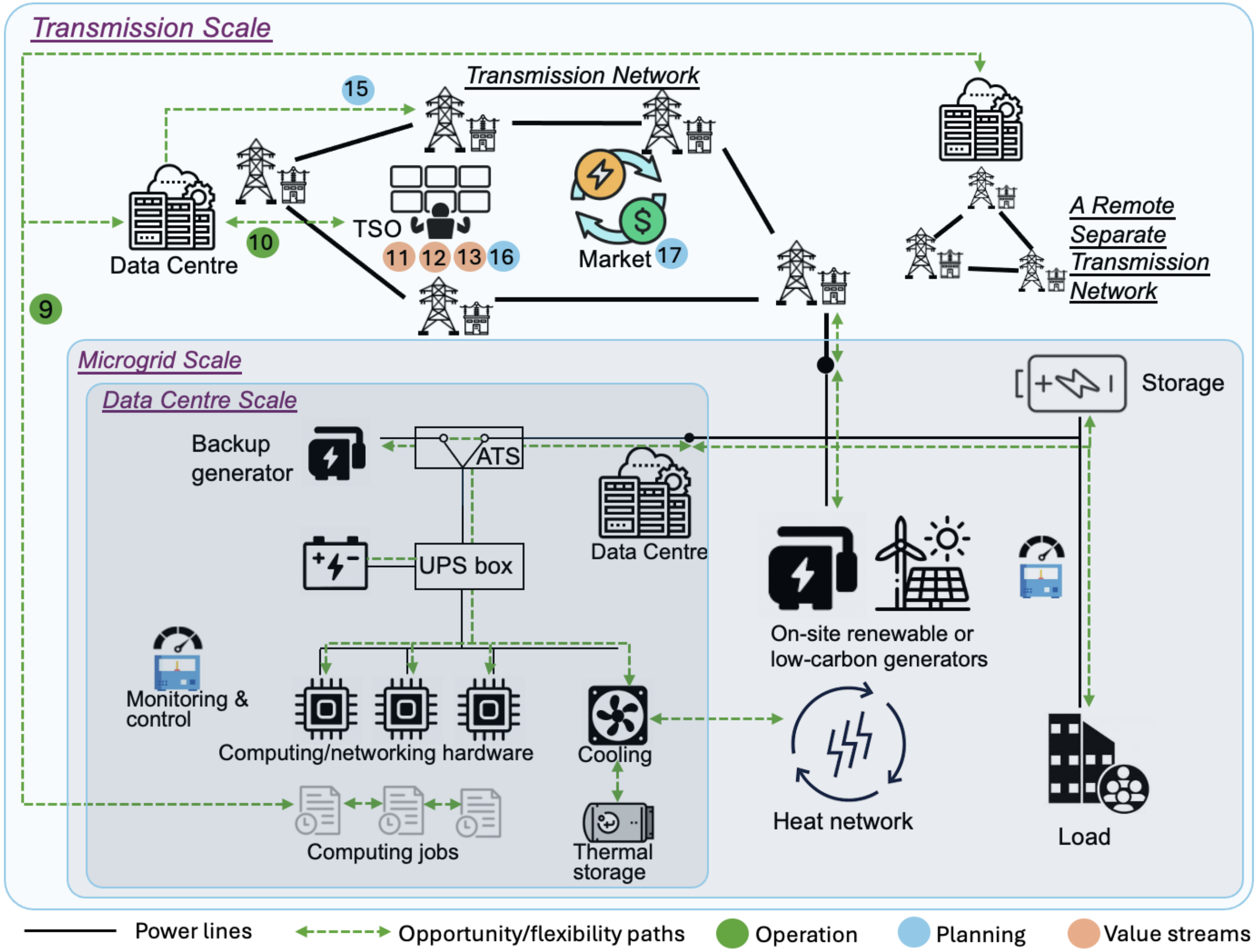
17 Data-centre-focused electricity market design

Value streams:

11 Grid flexibility service provision

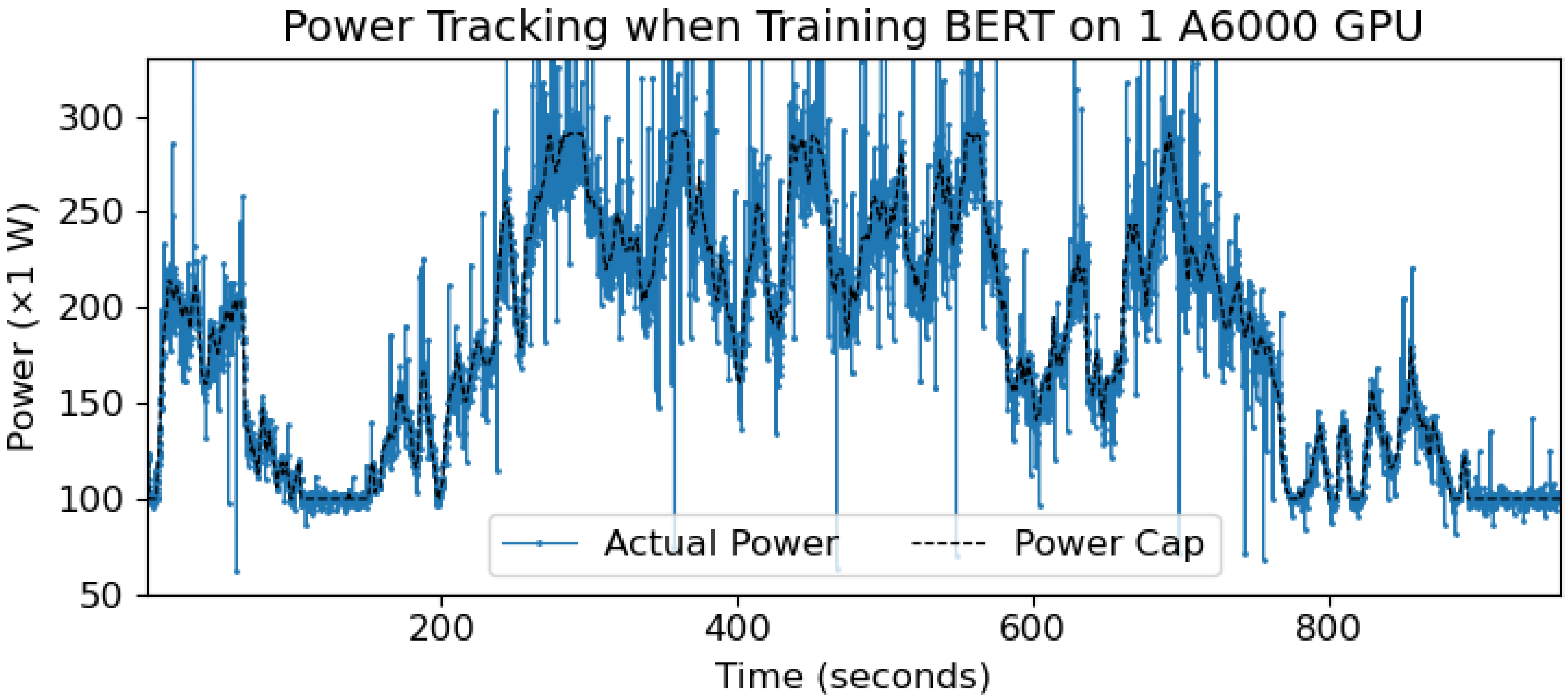
12 Grid upgrade deferral

13 AI hosting capacity increase



A Single A6000 Tracks a Stressed Real-World Dynamic Power Signal

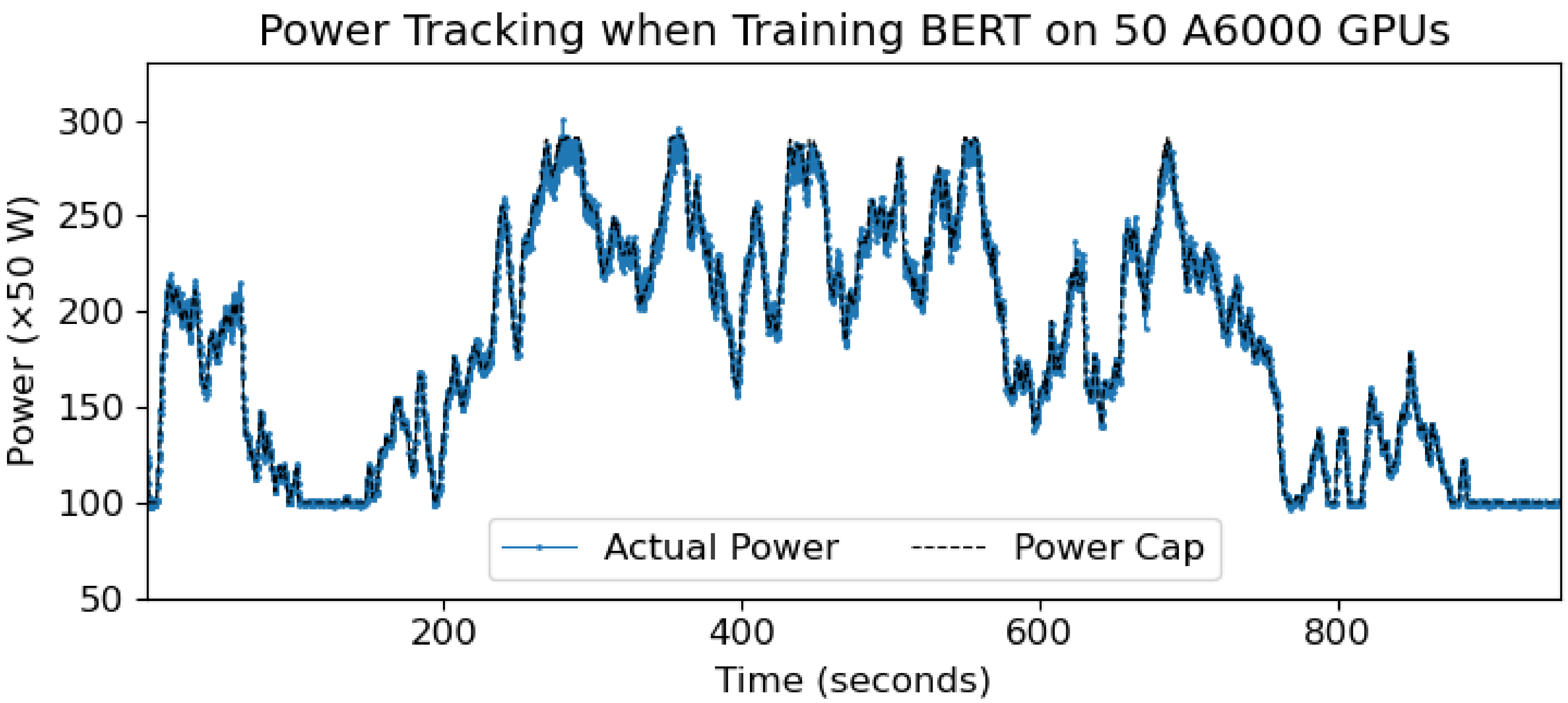
NVML power capping | 0.5 s control updates | Actual power vs requested cap



The controller remains responsive when the requested power target changes rapidly over time.

Aggregated Response Improves Smoothness Again

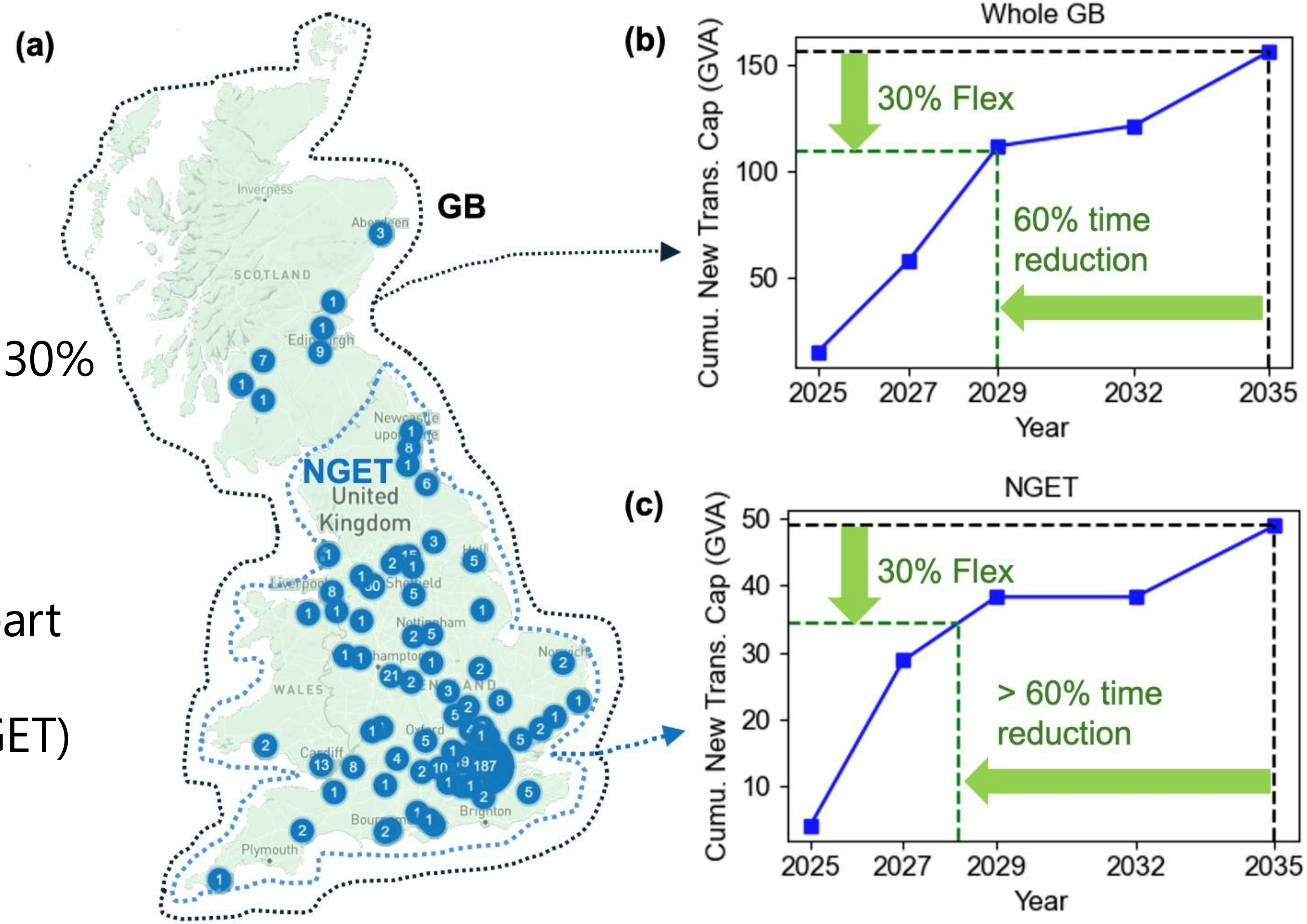
NVML power capping | 0.5 s control updates | Actual power vs requested cap



The aggregate 50-GPU response closely follows the requested signal across the full test window.

Value of Data Centre Flexibility for Grid Connection Speed

- Average UK data-centre connection time is 9 years (Ember, 2025)
- Reducing peak demand by 30% through flexibility reduces connection time by 60%
- This holds for both the full Great Britain grid and the part managed by National Grid Electricity Transmission (NGET)



Great Britain's data centre density map (www.datacentermap.com) overlaid with the boundary of the GB transmission grid managed by NGET.

Conclusions

- Takeaways:
  1. A challenge in AI data centres built-up is the lack of grid flexibility
  2. Flexibility opportunities spread across spatial and temporal dimensions, provided by: compute, cooling, and backup and primary generation/storage
  3. Grid-intelligent AI data centres can create win-win opportunities: faster connection, extra revenue, lower grid congestion.

- Further reading and relevant papers:
  - T. Morstyn, Y. Zhou, I. Whitfield, "Multiscale Grid Intelligence to Fight Artificial Intelligence Data Center Grid Defection: Unlocking a Faster, Cheaper, and Cleaner On-Grid AI Rollout," *IEEE Energy Sustainability Magazine*, 2026.
  - Y. Zhou, T. Morstyn, "Grid-Intelligent AI Data Centres for Primary Response," *IEEE Trans. on Industry Applications*, 2026.

Thanks!

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