Data Centre: Modelling, Opportunities, and Considrations

Overview of Data Centre Dynamics.

EPICS Workshop

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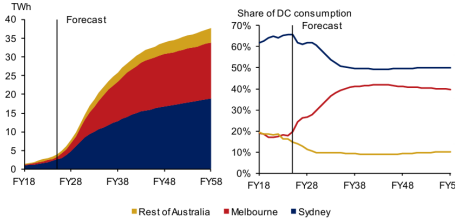
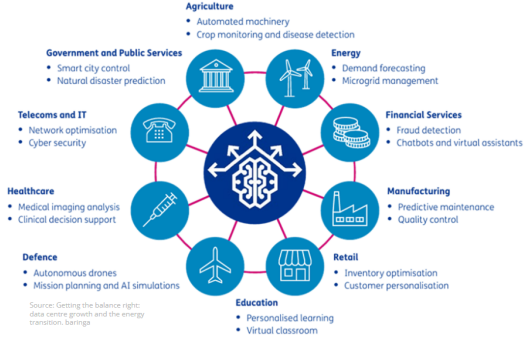
Rise of Data Centre Loads



Source: Oxford Economics Australia based on AEMO data.

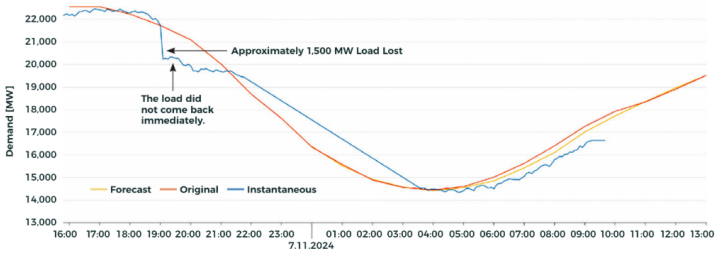
Data centre load forecast



- An average annual growth rate of **25.1%** is expected
- This research aims to answer questions around the data centre load **stability** and **dynamics**.

Risks of Data Centres

- Data centres are **highly sensitive** loads
- Two large data centre disconnections have happened in Northern Virginia:
  1. **1500 MW** disconnection in July 2024
  2. **1800 MW** disconnection in Feb 2025



Source: Practical Guidance and Considerations for Large Load Interconnections

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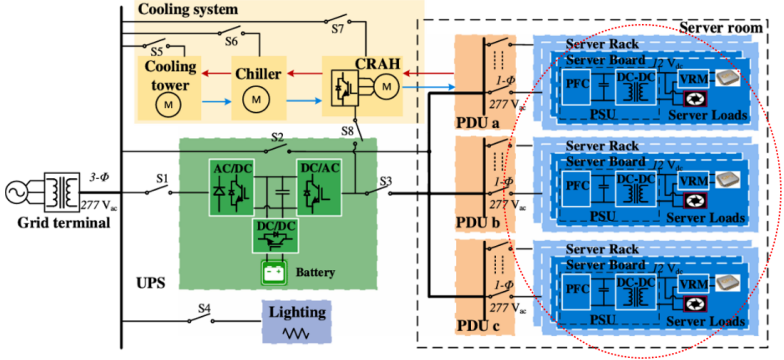
Data Centre Structure

- Data Centres have a **very high concentration** of **power electronic converters**.

- **Colling system:**
  - Modelled as a induction motor with drive.
- **UPS system:**
  - Online static
  - Offline static
  - rotary
- **Server room:**
  - Modelled as PFC units feeding a Constant Power Load (CPL)



Source: Dynamic Model and Converter-Based Emulator of a Data Center Power Distribution System

Data centre power distribution system

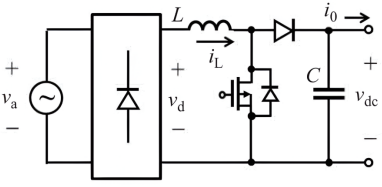
- The boost converter ensures the input current is **in phase** with the input voltage
- The Ideal PFC unit will behave like a **ressistor**
- The inductor current equation:

$$L\frac{\mathrm{d}i_L}{\mathrm{d}t} = |v_a| - (1-d)v_{dc}$$

- The capacitor voltage equation:

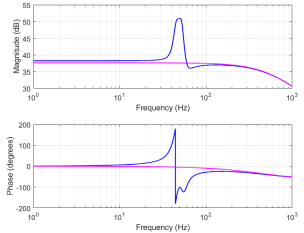
$$C\frac{\mathrm{d}v_{dc}}{\mathrm{d}t} = (1-d)i_a - i_0$$

- Due to these nonlinearities, a ω_p perturbation in input signals will result in perturbations at $\omega_p, \omega_p \pm 2\omega_1$ at the input signals.
- this changes the PFC input impedance



Source: Data Center Power System Stability– Part I: Power Supply Impedance Modeling

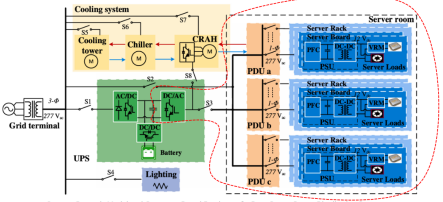
PFC unit structure



PFC unit input impedance with voltage control

PFC and Inverter stability

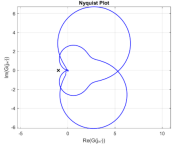
- In this research, **interactions** between PFC units in a data center and UPS inverter has been explored
- Poorly tuned **control** in the inverter, will cause **instability** and **oscillations** in the system
- **Nyquist criterion** can be used to determine stability

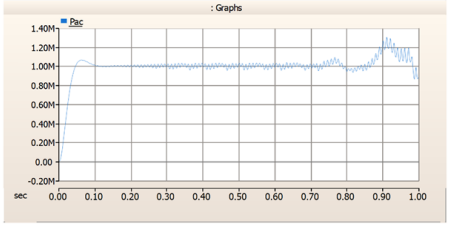


Source: Dynamic Model and Converter-Based Emulator of a Data Center Power Distribution System

Default values

Updated values





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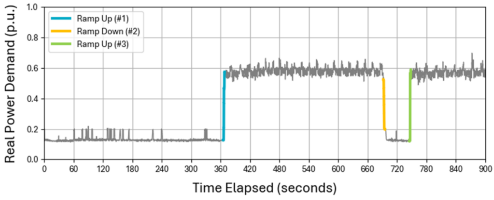
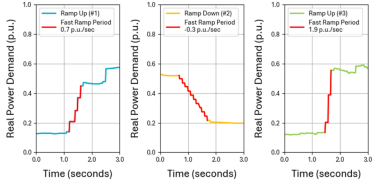
AI Training Load Patterns

- AI training often processes data in batches, using significant power in **computational phase**, and uses close to idle power in **communication phase**.
- At certain frequencies, the AI load pattern can interact with the grid's **natural modes of oscillation**, or cause **Subsynchronous oscillations (SSO)** in the grid.
- It can lead to power quality issues like **voltage flicker**.
- This pattern can have **fast ramp** periods.
- Possible solutions:
  - **STATCOMs**
  - **Grid Forming Inverters**



Source: Characteristics and Risks of Emerging Large Loads, Nerc



Source: Characteristics and Risks of Emerging Large Loads, Nerc

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Future Work

- Finding solutions to AI training load.
- Investigating interconnections between data centres and the grid.
- Presenting a simplified dynamic model for the data centre.


THANK YOU
Any Questions?