Data Centre: Modelling, Opportunities, and Considerations
Overview of Data Centre Dynamics

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1. Introduction

- Data centres are becoming a **major part** of the modern power system.
- Data centre consumption in Australia is expected to grow at an average annual rate of **25.1%** to reach 12.0 TWh by 2030 and 34.5 TWh by 2050.
- These loads are **highly sensitive** and can have rapid fluctuations.
- Data Centres have a very high concentration of **power electronic converters**.
- This research seeks to model the **dynamic behaviour** of data centres, investigate the **interconnections** between data centers and the grid, and find solutions to the **AI training load** fluctuations.

2. Opportunities and Hurdles

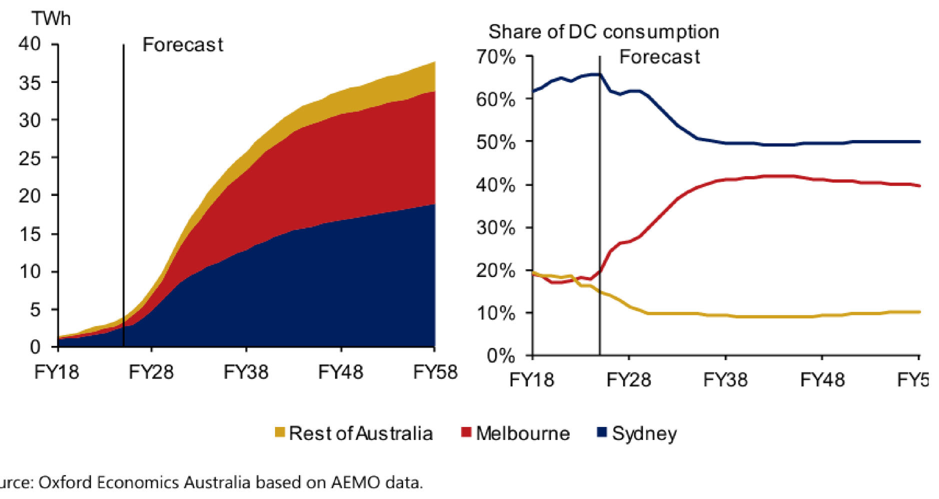


Figure 1: Data centre load forecast for Australia

Data centres are flexible loads that can open up vast opportunities for the grid:

- UPS storage:
  Grids can use their UPS storage to provide **Fast Frequency Response (FFR)** to sudden frequency variations.
- Thermal storage:
  Data centres can use their **thermal mass** and **store energy** by controlled overheating or overcooling by putting the indoor temperature within the acceptable limits.
- IT load:
  Data centres can change the amount of IT load they are consuming by 1) **Transferring the data** between geographically distributed data centres. 2) Moving the **delay-tolerant** loads from peak to off-peak times. 3) Using **Dynamic Voltage and Frequency Scaling (DVFS)**. This will degrade the data centre performance, which might be in conflict with the Quality of Service (QoS) agreement.

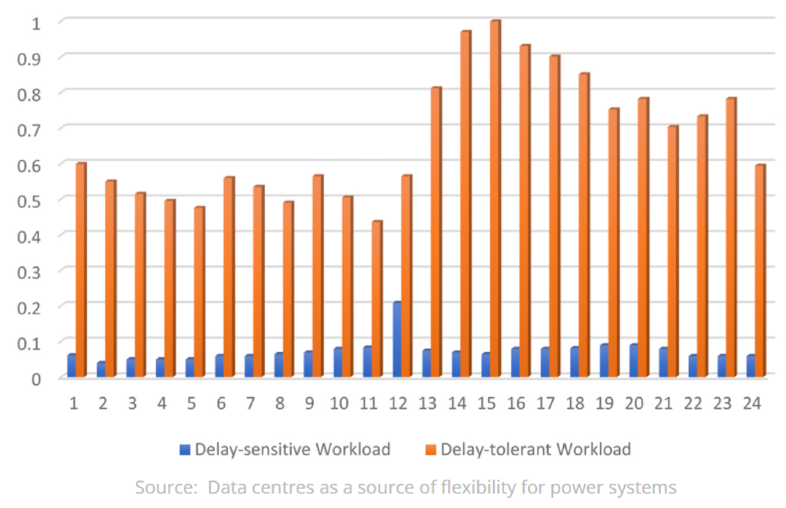


Figure 2: Comparison between delay-tolerant and delay-sensetive loads in a data centre

However, they are a **highly sensitive** large load that will **disconnect** from the grid during a fault, which will cause an increase in **frequency** and **voltage** and can worsen the situation for the grid.

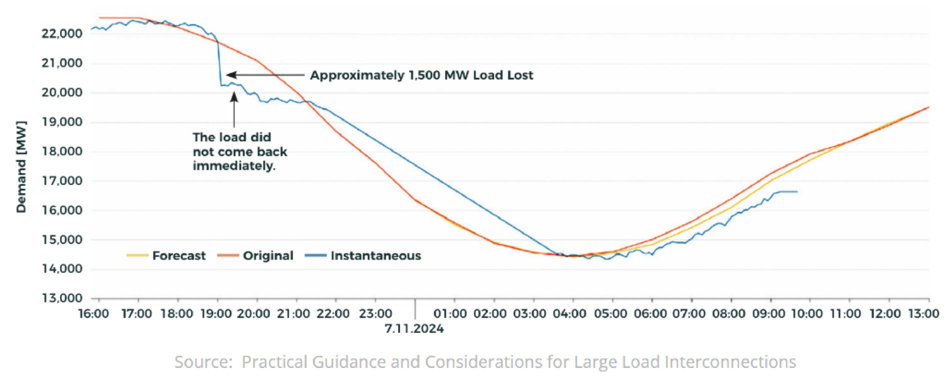


Figure 3: Large data centre disconnection in Northern Virginia, due to a fault in the grid

3. AI Load Pattern

- With the growth in **AI training**, this load pattern is becoming more prevalent in the grid.
- AI training often processes data in batches, using significant power in the **computational phase**, and close to idle power in the **communication phase**.
- At certain frequencies, the AI load pattern can interact with the grid's **natural modes**, or cause **Subsynchronous oscillations (SSO)**.
- It can lead to **power quality** issues like **voltage flicker**.
- they can fluctuate from minimum to maximum power in **sub-second** times.
- Possible solutions like **STATCOMs** and **Grid Forming Inverters** near data centres have been presented.

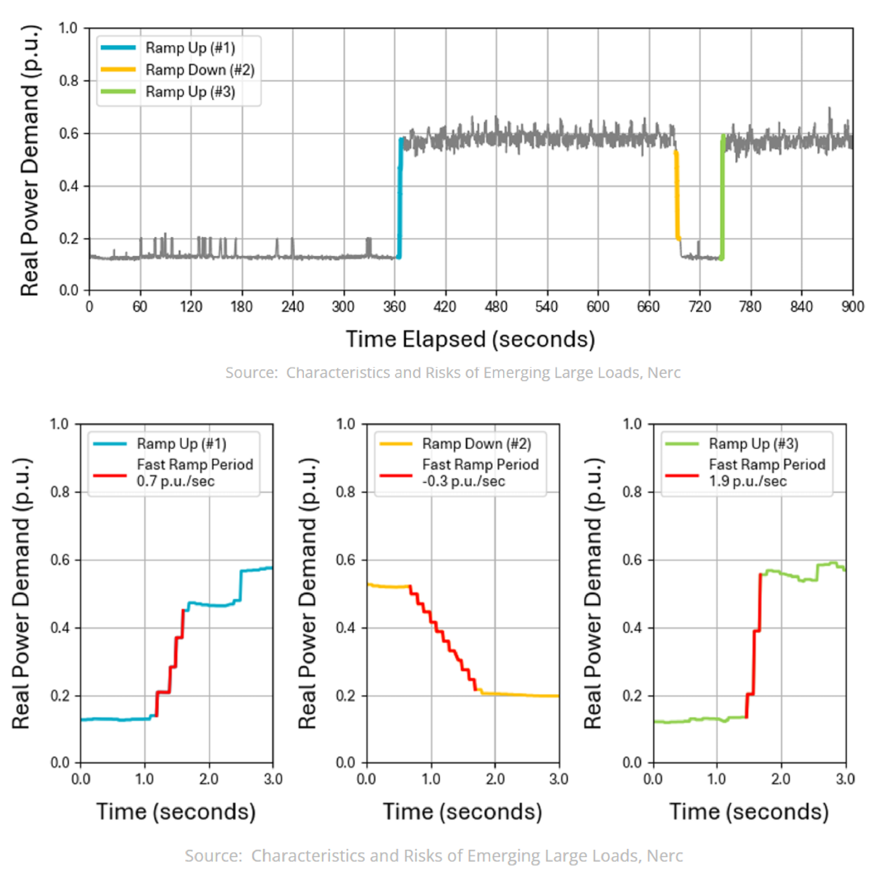
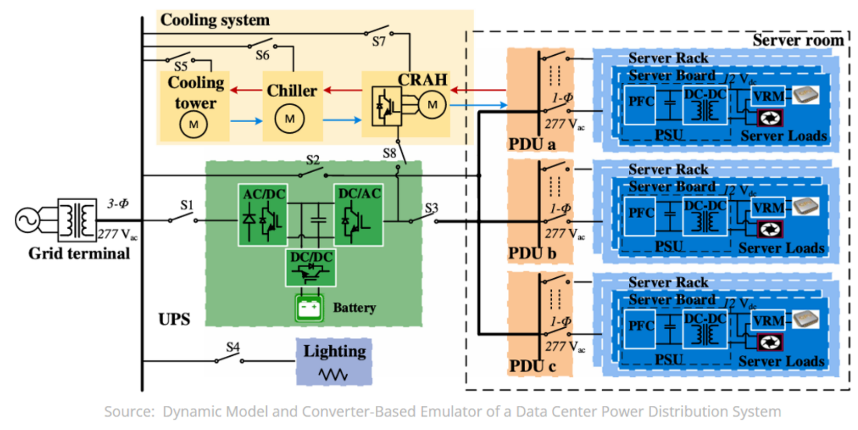


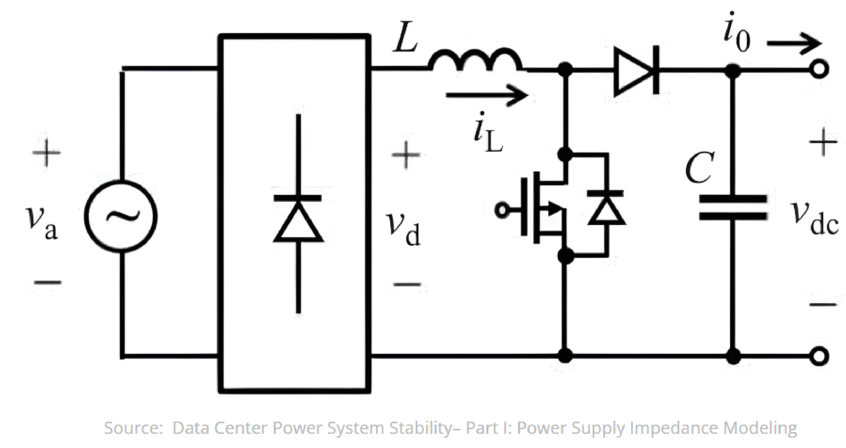
Figure 4: AI training load pattern

4. Data Centre Modelling



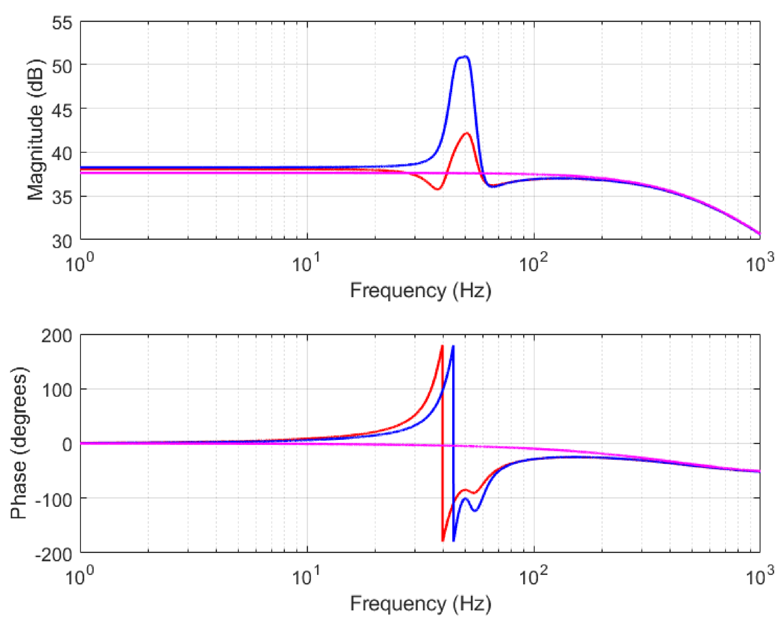
Data centre power distribution system

- From an electrical point of view, data centres are a large load with a high concentration of **power electronic converters**.
- The converters and their controllers might **interact** with each other or other devices in the grid.
- One possible cause of **instability** from data centres is the **Power Factor Correction (PFC)** unit.



Power Factor Correction Unit

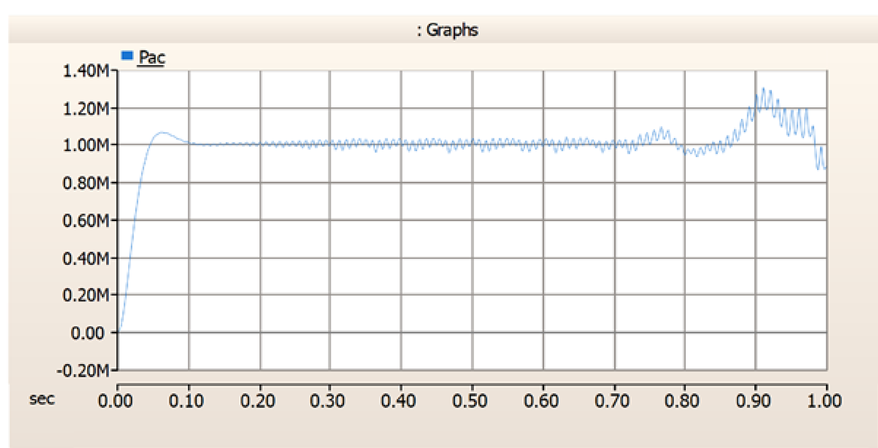
- The boost converter ensures the input current is **in phase** with the input voltage
- The **nonlinearities** in the **capacitor voltage equation** $C\frac{dv_{dc}}{dt} = (1-d)i_a - i_0$ and **inductor current equation** $L\frac{di_L}{dt} = |v_a| - (1-d)v_{dc}$ are the real source of instability.



PFC input impedance transfer function for 1) Fixed DC-link (Magenta), 2) controlled DC-link (Blue), 3) with grid impedance effect (Red)

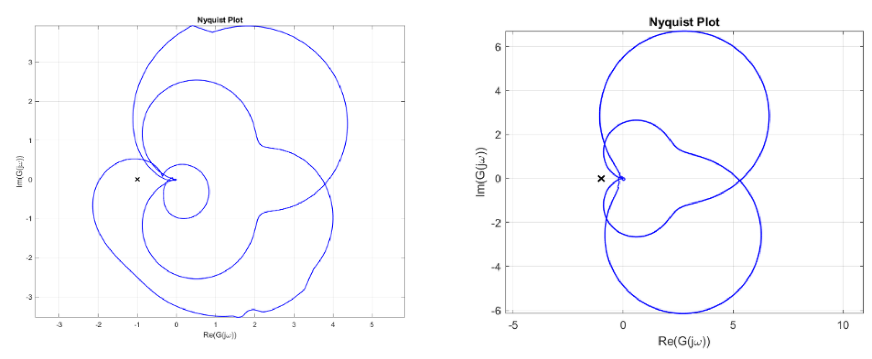
- A perturbed input with ω_p will cause perturbations at $\omega_p, \omega_p \pm 2\omega_1$ at the input signals. The resulting currents at new frequencies are called **coupled currents** and the phenomenon is termed **coupling over frequency**.
- This changes the PFC input impedance.
- The coupled currents can furthermore **interact** with the **grid impedance** and cause further voltage perturbation at those frequencies. This effect can further alter the PFC **input impedance** that is used for the Nyquist criterion.

Interaction between an inverter and PFC unit:



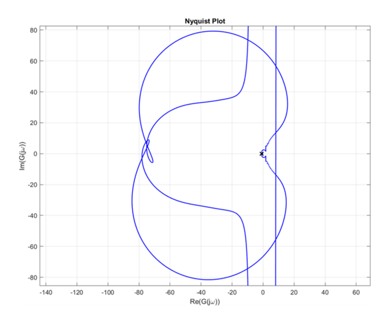
Instability between inverter and PFC units due to poor inverter control tuning

- In this research, **interactions** between PFC units in a data center and UPS inverter has been explored.
- Poorly tuned **voltage control** in the inverter, will cause **instability** and **oscillations** in the system.
- Decreasing inverters **input impedance** will help system stability



Nyquist criterion plots for inverter and PFC units positive sequence impedance with default values for inverter controllers and increased bandwidth controllers

- **Nyquist criterion** can be used to determine stability
- For the system to be stable, the plot should not **enclose** point (-1,0).
- The negative-sequence plot is the **mirror** image of the positive-sequence plot with respect to the x-axis.



Nyquist criterion plots for inverter and PFC units zero sequence impedance

- The zero sequence impedance for inverter is just the filter capacitor impedance
- Due to the instability in this sequence, at least one of capacitor or PFC units should be connected in delta configuration.

5. 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.