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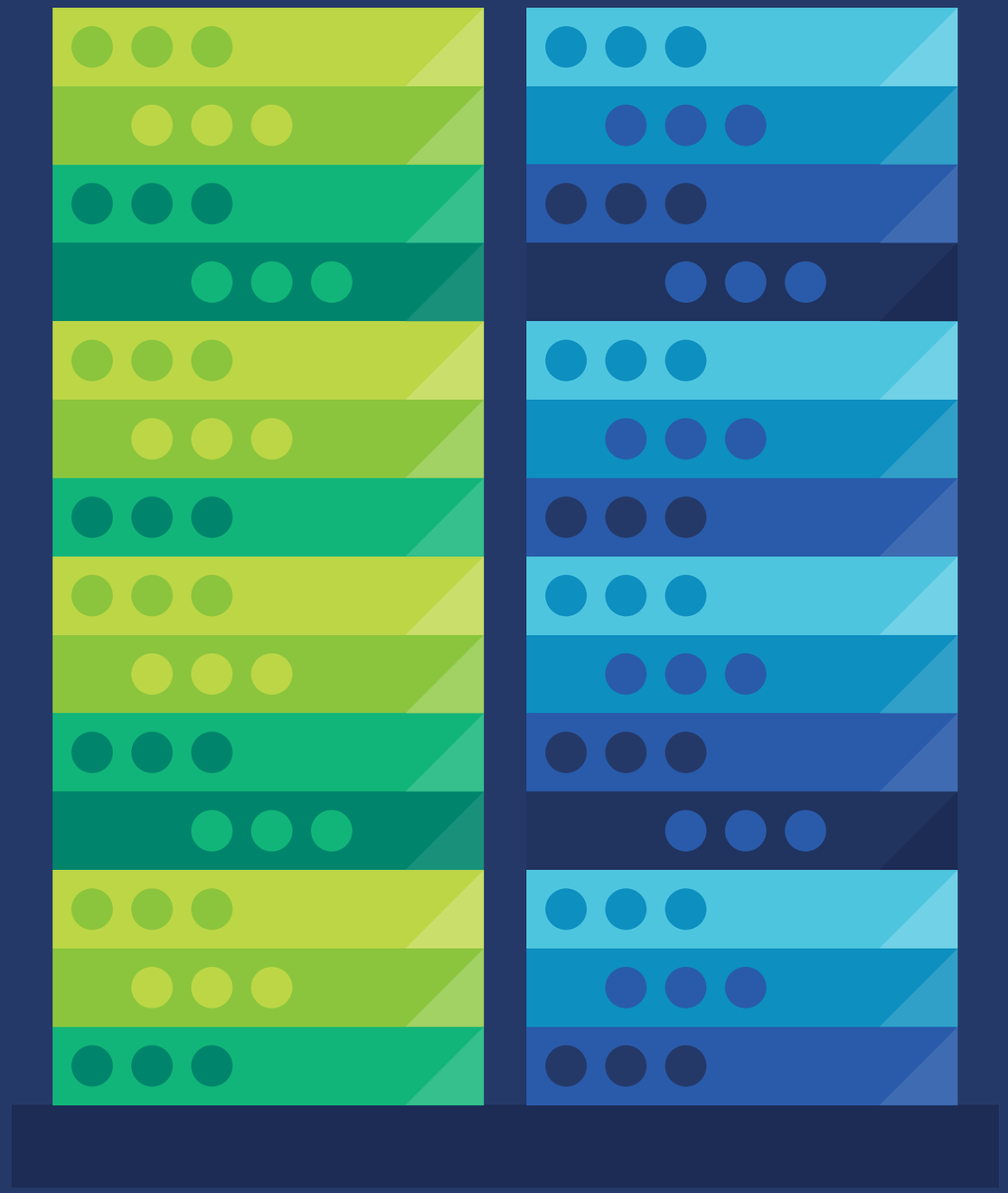
Integrating Data Centres

Prioritising power system integrity challenges in the NEM

White Paper – June 2026



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Acknowledgement of Country

AusNet acknowledges Aboriginal and Torres Strait Islander people as the Traditional Custodians of the lands on which we live and work. We pay our respects to Elders past and present, and celebrate their continuing connection to Country.

About the artist

As part of our reconciliation action plan we have commissioned an artwork by the artist Bitja (also known as Dixon Patten). A proud descendant of the Gunnai, Gunditjmara, Dhudhuroa, and Yorta Yorta tribes, with blood ties to Wiradjuri, Yuin, Wemba Wemba, Wadi Wadi, Monaro and Djab Wurrung, Bitja is deeply connected to his roots.

The artwork honours the strength in being part of a community, it honours our commonality as humans, but honours our diversity also and by having different views and experiences.

See AusNet's Reflect Reconciliation Action Plan

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Foreword

The emergence and expansion of large-scale data centres presents both significant opportunities and complex challenges for the National Electricity Market (NEM).

In Victoria, we are seeing this play out firsthand. Strong development fundamentals have seen clusters of new projects forming around key Victorian terminal stations, with GW-scale interest across transmission and distribution networks generating state significant benefits. At the same time, decision makers are grappling with how much of this load will proceed, with advanced interest already exceeding current system capacity.

This white paper was developed to give industry a clearer, more practical understanding of what that growth means for the power system in Victoria and NEM, including technical and operational implications of connecting and operating data centres.

It draws on our experience as the operator of the Victorian transmission network and Bespoke Energy's technical expertise enabling the safe connection on data centres. It is grounded in Australian and international evidence, particularly in markets with substantial data centre load and precedent of grid-scale disturbance events. Its focus is on power system integrity challenges – especially with the Victorian grid and how their integration differs from traditional loads.

The central finding is simple: data centres behave differently from the type of loads the NEM power system was historically designed for. As large inverter-based loads, they can respond to disturbances and signals in a way that is faster, less predictable and more likely to cause power system stability issues than traditional industrial demand. If unmanaged, these behaviours can have an adverse power system impact beyond our existing operational controls.

This matters because the upside is significant. The digital economy is forecasted to drive A$1 trillion in data centre investment across Asia-Pacific by 2030, with each GW capacity associated with up to A$22 billion of construction capital, hundreds of direct jobs and many more ancillary jobs throughout the wider economy.

This paper's message is that large-scale data centres can be integrated safely in our power system – as long as we take a considered, coordinated approach and with co-designed solutions grounded in real-world experience.

Sharing our technical insights with the broader electricity industry is an essential first step to address differing expectations about what is technically required and practically achievable. We have identified issues and solutions that will be relevant to jurisdictions across Australia seeking to safely integrate the rapid growth of data centres.

We also believe that the collective knowledge and experience of network operators, data centre proponents and market participants will be critical to developing coordinated frameworks and practical solutions that serve industry and end users. The issue is not unwillingness; it is limited mutual visibility of each party's perspectives, challenges, constraints and needs.

Lastly, we are encouraged by the progress already being made and remain confident that, through continued collaboration and the sharing of technical evidence, our industry can address the most pressing power system risks, and close process and information gaps. This recognises data centre design and operational behaviours are evolving at a faster pace than we have seen for other grid-connected plant.

We invite all stakeholders—industry leaders, technical professionals, and policy makers—to join us in this endeavour.

By working together, leveraging diverse perspectives and expertise, we can proactively support power system security and Australia's continued digital and economic growth.

Laura Walsh
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Managing Director, Bespoke Energy

Authors note

The information contained within this White Paper was developed by March 2026. We have not sought to update information to reflect new developments that may have occurred before publication.

Purpose

Share insights into the technical components of data centres and how they interact with the power system

Identify the most pressing power system integrity risks for data centre integration in Victoria and the NEM

Share our views on areas for industry collaboration: including a priority set of near-term actions to integrate data centres via a data centre enablement framework

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Executive summary

This Paper offers insights on data centre-power system interactions and a pathway to their safe integration

We share technical insights into how data centres interact with our electricity system and our perspective on the priority implications on system security, planning and operational decisions for both data centres and the wider power system as new development proceeds.

It also offers our views on a practical set of near-term actions (0-2 year period) to integrate data centres into the power system, built on collaboration between power system and data centre industries in the National Electricity Market (NEM).

Our approach leverages real-world Australian and international evidence and expert insight from AusNet and Bespoke Energy across grid connection, network planning and power system operations. We have not sought to conduct independent power system modelling.

While this Paper is largely centred on our experience in Victoria, its insights and actions are directly relevant to the NEM.[1]

What are power system interactions?

Power system interactions refer to the technical and operational consequences of data centre connection and operation for customers, data centre operators, the Australian Energy Market Operator (AEMO) and network service providers. Examples include how the exchange of energy between the data centre and the power system affects, or can be affected by, changes in frequency and voltage performance, power quality, protection adequacy, security of supply and the way different parties plan and operate their assets.

This Paper does not attempt to resolve issues outside of data centre related power system integrity challenges in the NEM. For example, other known challenges related to data centre integration in the power system (e.g. accuracy of demand forecasts, cost allocation) or other critical infrastructure requirements (e.g. efficient use of water).

Data centres are expected to grow rapidly worldwide, including in Victoria

Worldwide adoption of cloud-based computing and artificial intelligence services is forecast to drive A$1 trillion of investment in data centres within the Asia Pacific region by 2030.[2] Australian electricity network service providers are seeing this growth play out firsthand, observing an unprecedented wave of interest from data centre developers seeking connection to the national electricity market.

Victoria is now a hub for data centre development – reaching 338 MW of live IT capacity in 2025.[3] Its appeal is driven by strong development fundamentals including:

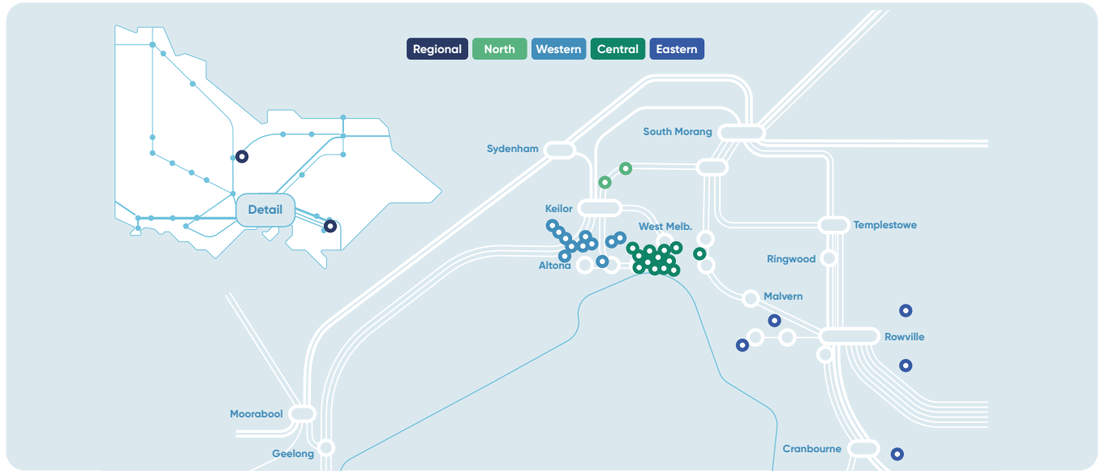
- larger, accessible land parcels
- timely and reliable grid connection
- access to a high capacity 500 kV transmission backbone
- relatively timely planning approvals
- strong fibre connectivity to Asia-Pacific
- a growing skilled workforce.

Further commitments from industry and the state government are expected to grow Melbourne as a cloud region.

Victoria is expected to increase its share of data centre demand in the NEM from approximately 25% today to 33% by 2030 and over 40% longer-term.[4] Clusters of future development are forming at key Victorian terminal stations and substations, with gigawatts (GWs) of interest across transmission and distribution electricity networks. While not all interest will proceed, advanced interest exceeds the current system capacity and is driving a race to connect. There has been an increased focus on efficiently coordinating data centres with existing and planned network capacity.

This Victorian data centre pipeline is a step change from development to date, which currently consists of predominantly smaller distribution-connected facilities centred around 'availability' zones in north, west and central Melbourne metro (see **Figure 1**). Today an individual data centre can be in the hundreds of MWs and beyond.

1. Note under Victoria's declared shared network (DSN) arrangements, VicGrid oversees planning of the Victorian transmission system and manages connection applications to this network including performance requirements and approval. AusNet owns, operates and replaces DSN transmission assets including high voltage lines, stations and connections. It also works alongside the Australian Energy Market Operator (AEMO) retaining operational responsibility to keep the DSN secure.
2. Moody's, APAC Data Centres: Dispersed growth, unique challenges report, 2025. Applied an exchange rate of 0.67 AUD/USD
3. Knight Frank, Data Centres The Asia Pacific Report, 2025
4. AEMO, 2025 Inputs, Assumptions and Scenarios Report, July 2025



▲ **Figure 1:** Map of operating data centres in Victoria[5]

Managed well, Victorian data centre growth brings benefits to our local economy and potentially our electricity system

In an increasingly digitised world, data centres play a central role in our everyday lives. As critical IT infrastructure, they provide a variety of consumer and business services ranging from high-performance computing and cloud services to AI productivity and automation tools. These digital interactions enhance living standards, productivity and innovation.

The digital economy is driving economic growth and now comprises about 15% of global GDP (~US$16 trillion), growing 2.5 times faster than the rest of the economy.[6] Each GW of data centres developed results between $A13-22 billion in construction capital spent, with additional value attainable through future expansion.[7] A typical hyperscale facility creates hundreds of direct, permanent jobs once operational. Each of these direct jobs helps to create 7.4 ancillary jobs throughout the wider economy.[8]

Data centres can also offer some benefits to the electricity system on a project specific basis. This includes funding network upgrades that other consumers use (i.e. terminal station establishment costs, new switchyards or transformers) and partnering with renewable developers to underwrite energy through power purchase agreements.

Chapter 1 covers the services data centres provide, their benefits, current state of development in Victoria, grid connection challenges and how the power system must evolve.

Safely connecting and operating data centres within our power system is a key challenge to unlocking their benefits

From a power system perspective, there is a growing appreciation that data centres' electrical behaviours are fundamentally different from traditional industrial loads. Most conventional large loads – such as factories and processing plants – are static, predictable and have well understood interactions with power system security.

Data centres on the other hand are a new class of inverter-based loads.

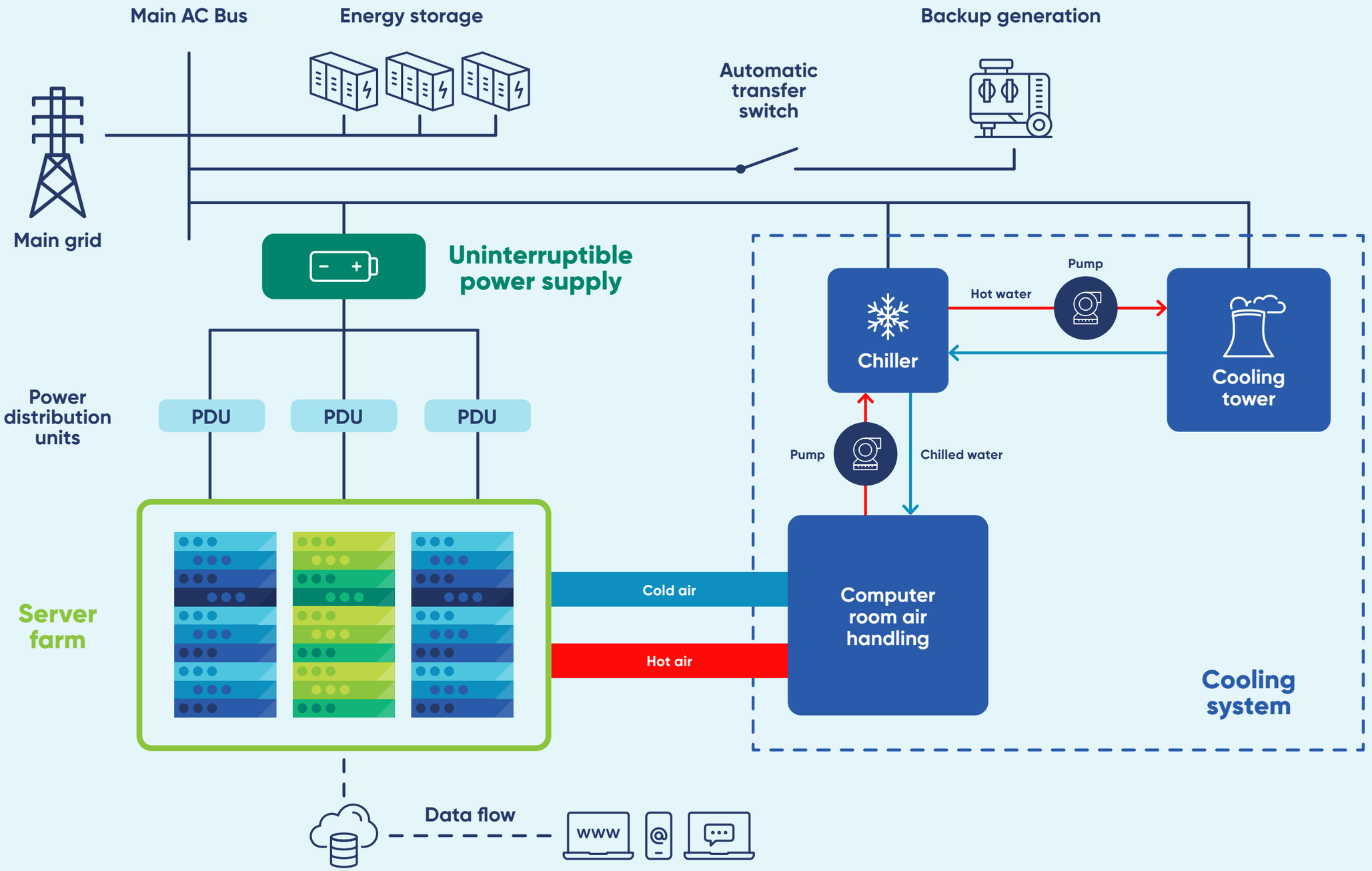
Data centres – key components and classification

From a grid interaction perspective, a data centre is best represented as two interacting elements:

a) the Server Farm, comprising large numbers of individual servers that perform data storage, processing, hosting and other activities, which sets the MW demand profile during normal operation.

b) the Uninterruptible Power Supply (UPS) manages the data centre's transition to stored energy, which determines how a data centre responds to a grid-side disturbance and the net-impact on the power system.[9]

5. RenewMap – as of 21/02/2026
6. International Data Center Authority, Global Digital Economy Report, 2025
7. Cushman & Wakefield, Data Centre Development Cost Guide, 2025. Applied an exchange rate of 0.67 AUD/USD.
8. CBRE, Data Centre growth has economic ripple effects article, 2024
9. Cooling Systems while critical to data centre operations are usually second-order priority as they typically only represent a small fraction of the data centre's power usage and interface size.



▲ **Figure 2:** A typical data centre components and interconnection[10]

10. Journal of IEEE transactions on automation science and engineering, A complete model for modular simulation of data centre power load, 2017

At a high level, data centre classification varies greatly across physical form (e.g. scale, siting and the balance of IT vs cooling loads), ownership (e.g. who controls workload scheduling and the practical demand-response envelope), functional role (e.g. specific workloads drive dynamic demand of power) and redundancy approach. These variations influence the net behaviour at the connection point.

Physical form	Ownership model	Functional role	Uptime tier
Enterprise (on premises)	Enterprise (on premises)	AI training or inference	Tier I Single path, No redundant components
Edge/Micro	Colocation (multi-tenant data centre (MTDC))	High-performance computing (HPC) / simulation / rendering	Tier II Single path, N+1 (one spare) components
Modular/ Containerised	Cloud / hyperscaler	Disaster recovery (DR)	Tier III Concurrent maintainability (dual A/B paths; N+1)
		Telecom / network	Tier IV Fault-tolerant, 2N (two independent full-capacity paths)
		Content Delivery Network (CDN) / edge cache	
		Price-sensitive compute	

▲ **Table 1:** Classification type summary

Chapter 2 provides an overview of the key components of data centres that affect grid interactions and how they are classified, as context for the deeper analysis of data centres and power systems in subsequent chapters.

The following unique behaviours have been observed and indicate that uncoordinated integration of data centres can have material system-level impacts:

Fault ride through and recovery capability for common power system faults

The ability for a data centre to 'ride through' (i.e. stay connected) to the power system during and after grid disturbances (i.e. loss of circuit, generator or load) is critical for maintaining grid stability.

The behaviour of large data centre loads during disturbances can have the same impact on the power system as large generators, because sudden drops or increases in energy consumption can push the frequency and voltage beyond safe operating limits triggering generator or load shedding.

For example, an abrupt reduction in load can result in over-frequency and voltage rise, prompting generator run-back or, in more severe cases, generator trips due to over-frequency generation shedding schemes. Whereas a large, coincident reconnection or rapid load ramp can contribute to under-frequency and activate automatic load shedding schemes.

Traditional industrial loads typically ride through short dips and continue drawing energy from the grid. By comparison, the involvement of data centres in large-scale system disturbances is a growing phenomenon internationally, with the impact on the power system aligned with the size of individual or geographical concentration of facilities.

International precedent confirms data centres may:

- detect a single disturbance and transfer critical load to their UPS and if conditions persist, on-site generation. To the grid this appears as a sudden MW drop followed by staged reconnection.
- remain online through a single dip but transfer to their UPS (or stage shutdowns) if multiple dips occur within about one minute (e.g. three dips in 60 seconds). Many data centre rooms move off grid together. This turns what is, electrically, a single transmission fault into a multi hundred MW event at the system level.

The initial transfer to backup or partial disconnection is only the first stage of the disturbance. Uncontrolled or overly rapid reconnection of large blocks of load during recovery can cause significant swings in frequency and voltage, effectively creating a second contingency. Practical experience has shown that staged reconnection, defined ramp rate limits at the connection point, reduces this risk and supports stable system balancing.

Fault ride through outcomes are highly sensitive to project-specific voltage and frequency protection thresholds and settings (transfer logic, successive-disturbance tolerance and reconnection profile) and power system performance standards. In most previous international incidents, data centres were connected under standards materially less stringent to those applied to inverter-based resources, although this is changing with new requirements being proposed across various jurisdictions.

Chapter 3 steps through how data centres differ from other loads, explores typical load profile and ramping behaviours and lessons from documented international experience disturbance events.

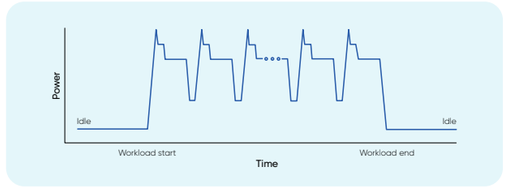
Rapid ramp rates and pulsing demand

Data centres can change their electricity usage with computing loads ramping up or down at a rate much faster than anything the power system has dealt with before. These sudden and large demand changes typically occur independently to prevailing power system conditions.

There are a wide variety and scale of data centre load profiles observed today, with rapid ramping behaviour driven by application-specific tasks and workloads. Facilities primarily used for cloud computing have variable loads and seasonal spikes. Data centres that host AI training, gaming or media streaming events have computationally intensive "bursts", with large variations in power and cooling requirements. Further information on these different load profiles is available in Section 3.2.

Large inverter-based loads can ramp bidirectionally at rates of hundreds of megawatts in seconds, which impact the grid even when these sites are operating normally.[11] In some operating modes, demand changes exhibit second-scale swings and step-like variations that can become system-visible when many data centre racks or halls align. This is particularly concerning when multiple large loads are geographically concentrated.

The figure below shows a typical AI-compute power trace: a rapid ramp-up from idle to high load, followed by coincident seconds-scale swings during the run and a rapid ramp-down at job end.



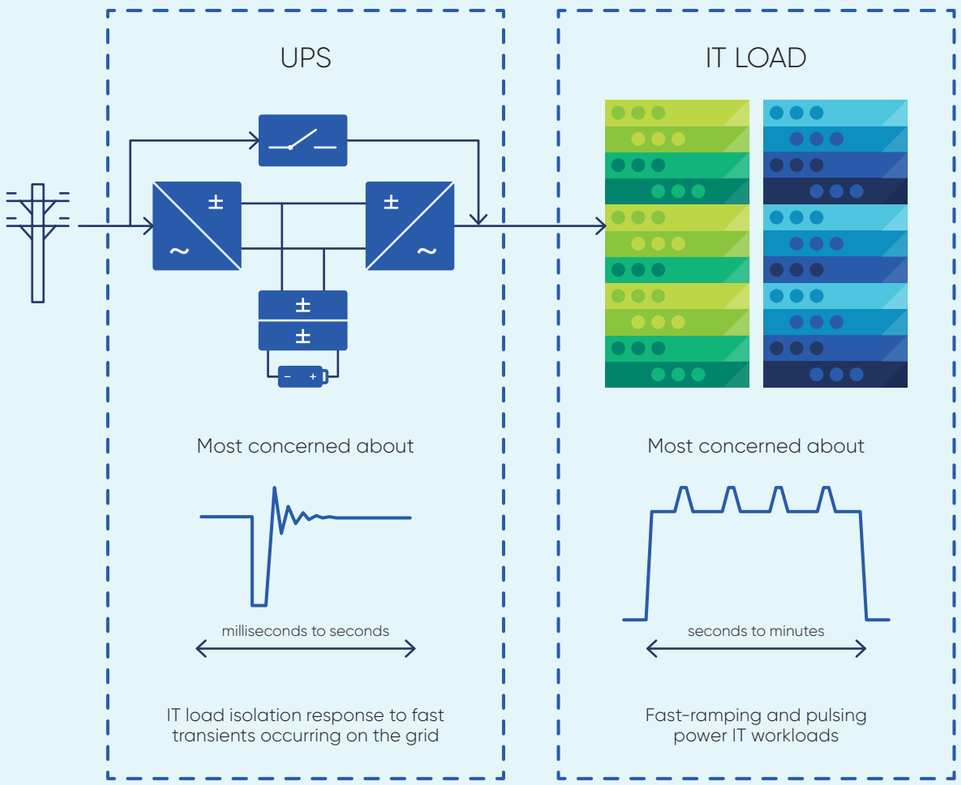
▲ **Figure 3:** Coincident AI-workload power profile (fast ramp-up, repeated spikes, fast ramp-down). Source: Confidential

Start-stop, pulsing load profiles like those caused by AI computes can challenge a power system when the magnitude of the pulses reach single MWs at the distribution network level or extend into tens of MWs at transmission level. Appearing as a forced oscillation on the network, such large, rapid power swings have the potential to unduly trigger frequency control mechanisms, cause power quality standards to be breached (e.g. voltage flicker), or even excite instabilities in the power system (more on this in subsequent sections).

Depending on the timescale of the power swings, this behaviour can increase the frequency of mechanical and discrete control actions, such as tap changer operations and switched shunt capacitor or reactor switching, with implications for asset wear and service life. These impacts scale with data centre size and are strongly context dependent.

Technological advancements mean this is a rapidly evolving space and we anticipate that ramping behaviours will become less peaky over time. Some data centre proponents are working with OEMs to develop rack-level controls that help smooth data centre load behaviour and address active power variation at the grid side. These controls are available on some new systems but are still emerging technologies and are not universally adopted.

11. NERC Large Loads Task Force (2025), Characteristics and Risks of Emerging Large Loads, July 2025.



▲ **Figure 4:** Primary power system integrity challenges as they relate to data centre components

Primary power system integrity challenges as they relate to data centre components

Figure 4 links the two above mentioned power system concerns to the simplified major components of a data centre.

The UPS determines when and how to disconnect from or reconnect to the grid. It therefore plays a pivotal role in either mitigating or amplifying concerns around a lack of fault ride through and recovery capability during a disturbance.

The IT load determines the primary power demand drawn from the grid during normal operation. It therefore determines the sudden changes in the short-term power-draw impact of data centres (ramp rates), which can impact network asset lifetimes, trigger grid-scale control schemes and erode headroom on frequency control equipment and markets.

Risks of frequency instability

Large-scale, near-instantaneous data centre disconnections (i.e. mass transfers to backup) create a positive contingency (where generation exceeds load) so frequency rises quickly and regulation/primary controls must arrest and return it to nominal frequency.

A recent US Eastern Interconnection event illustrates the potential for an observable frequency response from disturbance driven data centre disconnections. In July 2024, approximately 1,500 MW of voltage-sensitive data centre load reduced within 82 seconds during a reclosing sequence, pushing frequency up to about 60.05 Hz before settling back to 60 Hz in four minutes.[12] The generating capacity of the Eastern Interconnection system is roughly 10 times larger than the NEM. The same loss in a smaller system, such as the NEM, would have the potential to cause a larger frequency deviation and increase the minimum inertia (or equivalent fast frequency response) needed to maintain secure frequency performance.

The volume of contingency frequency control ancillary services (FCAS) procured within a given NEM region gives consideration to the single largest credible contingency. In Victoria, the largest allowable contingency is 600 MW designed to cover the potential loss of the largest industrial load or the Victoria to Tasmania interconnector. It is currently less than in other states. We welcome the rapid increase in BESS being commissioned in the NEM with a high degree of frequency capability. However unless limits are raised, data centre projects are expected to exceed this contingency increasing risk that FCAS is eroded beyond existing limits.

In system normal conditions, seconds-scale AI clusters widen short-term frequency deviations and also increase the duty on frequency control and reserve provision. This recognises frequency balancing processes are tuned for many small, uncorrelated variations, not step-changes of hundreds of megawatts.

These frequency impacts are best managed by prioritising the underlying drivers (ride-through and recovery expectations and ramp envelopes) rather than treating “frequency instability” as a standalone primary risk. A higher contingency event size to account for large data centre loads is another possible solution worth investigation. A change to the market could be allowed that enabled data centres to procure FCAS to cover their impact.

Risk of forced oscillations

Power electronic control algorithms and faulty equipment have the potential to cause persistent oscillations in the system frequency independent of grid conditions, which can lead to resonances.

Variations in data centre IT load profile can potentially create periodic low-frequency power oscillations up to 3 Hz, which are within the natural modes[13] of power system electromechanical oscillations. Recent international incidents also show that data centres can trigger higher-frequency control-induced oscillations in the 10–30 Hz range caused by power electronic controls rather than IT load variations. In addition to control algorithms operating as intended, forced oscillations can also originate from power electronic controls, for example mistuned controllers or firmware defects in inverter or UPS systems.

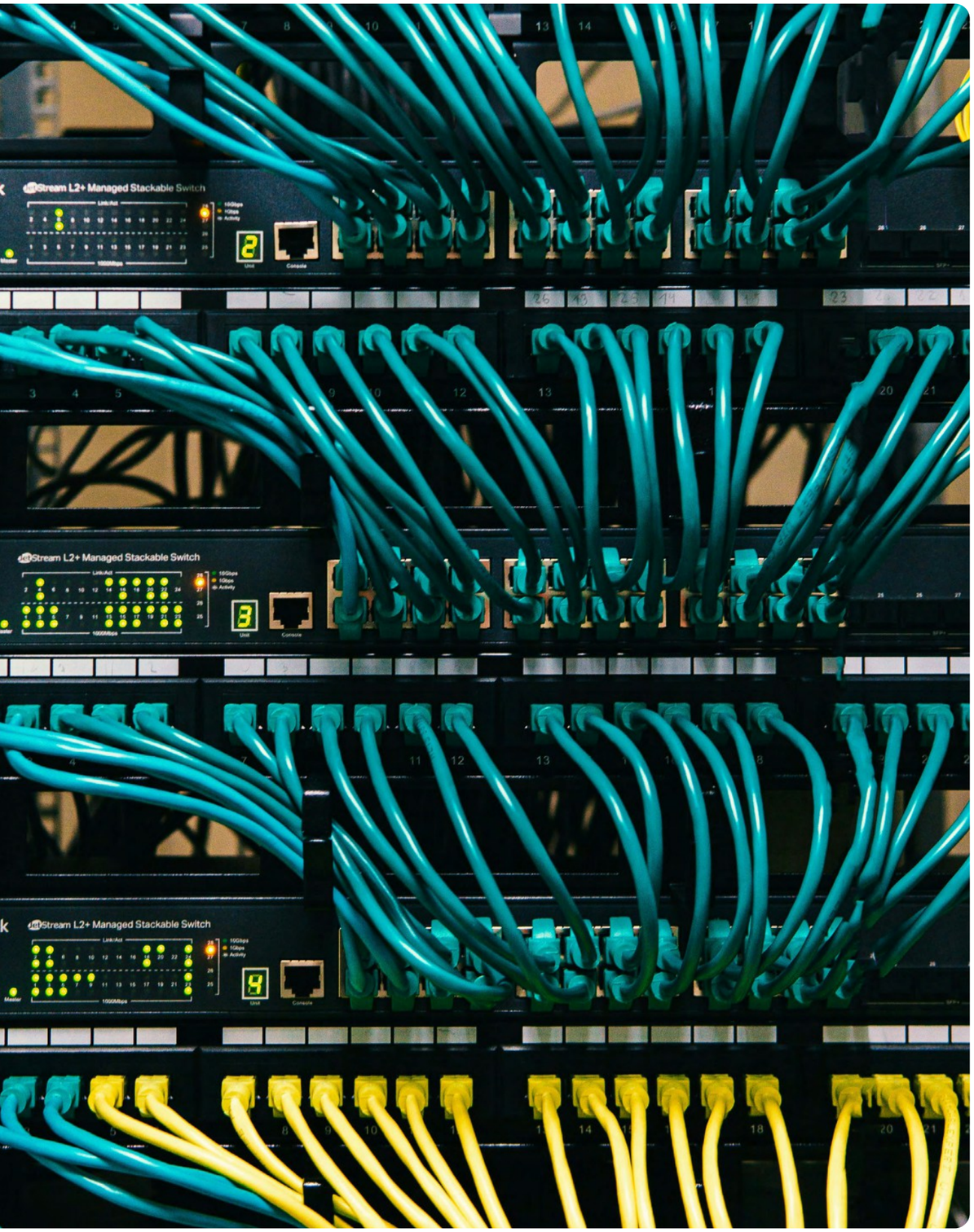
Forced oscillations occur when a load or generation source introduces periodic disturbances, independent of grid conditions, at frequencies near these natural modes. These oscillations can propagate across the system, potentially leading to resonances which result in tripping of generators, load, or network elements on self-protection.

Victoria has already seen examples of power system oscillations driven by inverter-based renewables during periods of low system strength, with no evidence that data centres are immune to such scenarios.

Targeted investigations using fit-for-purpose dynamic representations and monitoring of new data centre installations can help improve knowledge of these issues as they apply to inverter based-loads. Mitigation measures in documented international incidents have typically involved firmware updates, controller retuning and where necessary, temporary MW caps while fixes are validated.

Chapter 4 considers the disturbance set relevant to data centres, the Victorian planning context, and what power system performance requirements are emerging internationally.

12. North American Electric Reliability Corporation, Incident Review—Considering Simultaneous Voltage-Sensitive Load Reductions, Jan 2025.
13. A natural mode is a natural resonant frequency and damping ratio that a power system may have due its inherent topology and components.



Data centre behaviours are new to the power system and we are still developing robust tools and processes to manage them

The data centre behaviours explored in this paper are relatively new to power systems internationally and in Australia.

It should be no surprise that the NEM does not yet have all the necessary planning and operational tools in place to model and anticipate the speed, coincidence and variability of inverter-based loads. This plays out in a number of ways:

- **Unknown performance**

  The industry does not currently have a suite of representative, validated models of data centre behaviour, nor does it have consistent real-time monitoring of how these facilities actually perform once connected.

  Without accurate models and operational data, planners and operators cannot effectively assess dynamic interactions, system strength impacts or the cumulative effects of many similar connections. This lack of understanding inevitably leads to conservative assumptions in some areas and blind spots that can miss key behaviours of power-electronic front ends and site controls. Neither supports efficient investment or secure operation.

  Detailed dynamic models can and are being developed for key data centre technologies. This suggests that the main barrier is not necessarily technical capability or lack of willingness, but the lack of a unified framework that clearly defines modelling requirements and improves real-time visibility at data centre connection points.

- **Collaborative processes are still maturing and not publicly visible**

  Processes to collaboratively learn about new data centre design and operational capabilities, or to continuously improve how data centre integrations are being handled, are still developing. Network service providers, system operators, data centre developers, equipment manufacturers and commissioners all hold pieces of the puzzle.

  More can be done to leverage existing collaborative processes to coordinate insights, share operational experience, or refine technical management approaches. To the extent possible, these processes should actively encourage participation and aim to publish insights publicly.

- **Undefined management requirements**

  Technical requirements for inverter-based loads are either not fully specified or are inconsistently applied across the NEM. In Victoria, recent guidelines have updated performance, modelling and study requirements for transmission-connected data centres and are – at present – more comprehensive than distribution-connected facilities of a similar size and nature.

  There is work underway by the Australian Energy Market Commission (AEMC) to design and implement technical requirements across the NEM.[14] While offering a more consistent approach than currently exists, requirements at state and NEM level must continuously evolve to respond to real-world performance capabilities and risks identified in this paper (e.g. ramp rate limits and start-up and shutdown controls).

  Compliance with intended performance is not currently consistently monitored. This recognises that without data centre-specific requirements and sufficiently detailed models, performance cannot be specified, demonstrated or verified consistently.

  Further, approaches to optimise network planning decisions to account for "size creep" (i.e. data centres that begin small and receive multiple expansion approvals) are still evolving, particularly for distribution connected plants.

Chapter 5 identifies the areas at the data centre and grid interface that most need addressing – including process and information gaps and the most pressing power system performance issues for Victoria and the NEM.

14. AEMC, Improving the NEM access standards – Package 2, Draft rule determination, March 2026

AusNet sees four areas in which our electricity sector can respond to the data centre industry as it grows and evolves

AusNet is proposing the power system and data centre industries work together on a proactive, coordinated approach to accommodating data centres, which supports power system security and Australia's continued digital and economic growth.

The current data centre landscape bears a striking resemblance to the initial renewable energy surge between 2017-2019. We see opportunities to draw on the lessons of the integration of renewables and complement other related work already underway in the NEM.

These areas have formed the basis of our data centre enablement framework. We encourage further conversation about this framework and are open to exploring additional actions or constructive changes that may support its intent.

Chapter 6 proposes a data centre enablement framework that brings insights from previous chapters together in a set of near-term priority actions for the power and data centre industries to collaborate on.

We see four areas in which the electricity sector can respond:

1 Connections

Fit-for-purpose requirements

Establishing fit-for-purpose NEM-wide performance requirements for transmission and distribution-connected inverter-based loads enables data centres to deliver predictable behaviours that support system security, while accelerating the overall connection process. Clear expectations around fault ride-through performance, acceptable active power ramp rates and oscillatory behaviour reduce uncertainty and prevents adverse interactions as penetration increases.

Modelling and predictability

Consistent and robust connection modelling requirements are essential to improving understanding before assets connect, as it is far cheaper to identify and remediate issues before construction than after operation begins. Requiring high-quality, representative models enables network service providers to assess risks accurately and proportionately, particularly where multiple data centres may interact.

2 Planning

Network plans

Using state transmission plans to proactively guide data centre development addresses the collective risk. By signalling where the network can efficiently support large new loads, these plans can help steer investment to appropriate locations, reducing congestion, system strength challenges and inefficient network upgrades.

Transparency and reporting

Furthermore, collecting and publishing load connection information improves transparency and system-wide awareness of how fast and where change is occurring. This visibility is a prerequisite for network planners and operators to anticipate emerging risks rather than reacting after problems materialise.

3 Operations

Monitoring and reviewing operational mechanisms

Improved real-time visibility of inverter-based loads addresses operational uncertainty. Understanding how data centres are actually behaving in real time and in high definition creates the foundation for secure system operation, as these loads become a dominant feature of demand and allow for validation of the models used for future connection and planning studies.

Exploring operating implications, including potential new mechanisms, required to manage a future with a high penetration of large loads – for example, outage planning and FCAS contingency procurement.

4 Engagement

Open collaboration

Leverage existing technical working groups to collaborate on foundational integration issues. This includes encouraging shared learning, coordinated evolution of standards and continuous improvement as technology and system conditions evolve.

1 Unlocking the benefits of data centres

Key messages

- Data centres enable digital interactions that underpin our standard of living (e.g. cloud services, AI tools) and are driving global GDP growth 2.5 times faster than the rest of the global economy.
- Australian electricity network service providers are observing unprecedented levels of data centre connection interest. AEMO forecast 22 TWh of electricity consumption by data centres in the NEM by 2035 and more than 28 TWh by 2040.
- Victoria is now a hub for data centre development with strong commitments from both industry and government to grow Melbourne as a cloud region. Live IT capacity has reached 337 MW – a 25% increase from 2024.
- The vast majority of existing Victorian data connected facilities are clustered in and around Melbourne. Development to date has predominantly been smaller distribution-connected facilities centred around the northern, western and central metropolitan regions.
- Large clusters of future development are forming at key terminal stations and substations. While not all interest will proceed to connection, advanced data centre development across distribution and transmission-connected facilities far exceeds current system capacity, with a race to connect underway. New terminal stations on or near the 500kV system are expected to offer a simpler and faster development pathway for data centres to connect.
- Data centre developers and their equipment manufacturers are currently encountering an inconsistent landscape when attempting to connect large data centres to the NEM.
- Across the NEM, efforts are underway to build an electricity system that supports data centres – including improving demand forecasting, coordinating the efficient build of electricity infrastructure and identifying pathways to safely integrate them into the power system.

This chapter introduces:

- The services and benefits data centres provide (Section 1.1)
- The current state of data centre development in Victoria (Section 1.2)
- Data centre operators' challenges navigating the grid connection process (Section 1.3)
- How the electricity system must evolve to enable data centres (Section 1.4).

1.1. How data centres benefit Australia – a power perspective

Australian electricity network service providers are observing an unprecedented wave of data centre connection interest at both transmission and distribution levels. Data centre developers are responding to rapidly growing global demand for cloud-based computing and artificial intelligence (AI) services, which require data to be monitored, analysed, stored and transferred.

In 2025, AEMO recognised this trend, forecasting more than 22 TWh of electricity consumption by data centres in the NEM by 2035 (7% of total forecasted grid-supplied electricity) and more than 28 TWh (10% of total forecasted grid-supplied electricity) by 2040.[15] By contrast data centre demand accounted for just 4 TWh, or 2% of grid-supplied electricity in 2024-25.[16]

The sustainable connection of data centres can unlock significant benefits for Victorians and Australia more broadly, including:

- Enabling digital interactions that enhance living standards
- Driving economic growth
- Creating high-skilled jobs

Data centres can also offer some project specific benefits to the electricity system including:

- Fast-tracking and funding network infrastructure
- Underwriting corporate renewable energy market

See overleaf for more information.

15. AEMO, Draft 2026 Integrated System Plan, December 2025
16. AEMO, 2025 Inputs, Assumptions and Scenarios Report, August 2025

Economic benefits unlocked from data centres

These benefits will continue to increase as consumption and scope of data and AI services grow overtime. Research by the International Data Centre Authority expects AI to contribute to a 21% net increase in US GDP by 2030 and have a similar effect across the world.

Enabling digital interactions

Digital interactions enhance the living standards of Australians via:

- Communication (email, instant messaging, social media, video conferencing).
- The 'Internet of things' (Wi-Fi and 5-G enabled wearable devices, home appliances, vehicles and equipment).
- Cloud service delivery (e-commerce, navigation, banking, education and learning, healthcare, defence).[17]
- AI tools (high reasoning models, creative models, productivity and automation tools).

Driving economic growth

- The digital economy currently comprises about 15% of global GDP (~US$16 trillion) and is growing 2.5 times faster than the rest of the economy.[18]
- The rapid adoption of AI and cloud technologies and increasing demand for data sovereignty is expected to drive more than A$1 trillion of investment in the Asia Pacific region by 2030.[19]
- Each GW of data centres developed results in between A$13-22 billion in construction capital spent, with additional value attainable through future expansion.[20]

Creating high-skilled jobs

- In 2024, there were 9,600 data centre operation jobs in Australia, which is expected to reach 17,900 jobs by 2030.[21]
- A typical hyperscale data centre creates thousands of jobs during construction phase and hundreds of direct, permanent jobs once operational.[22]
- Each direct job in the data centre industry helps to create 7.4 ancillary jobs throughout the wider economy.[23]

Project specific electricity system benefits

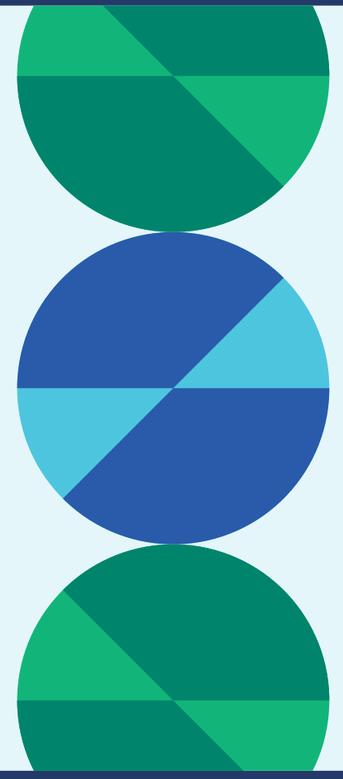
Fast-tracking and funding network infrastructure

- Data centre projects fund 100 per cent of the costs associated with their connection to the transmission network.
- Some data centre developers fund a 'shared' network required to facilitate their connection (i.e. terminal stations, switchyards, transformers). Funding these new assets can expedite augmentation projects requiring regulatory approval within existing network plans and reduce costs to the wider electricity customer base.

Underwriting corporate renewable energy market

- International hyperscalers are partnering with renewable developers as "anchor tenants" underwriting 49% of global corporate clean power purchase agreements.[24]
- Australian data centres underwrite 1.5 TWhs of energy through power purchase agreements annually.[25]
- Potential to co-locate data centres with renewable energy and storage facilities to provide grid support.[26]

Unlocking these benefits requires stakeholders to work together to develop the right supporting infrastructure, systems and processes. We discuss this further in section 1.4.



17. Deloitte, Powering Asia Pacific's data centre boom, 2026
18. International Data Center Authority, Global Digital Economy Report, 2025
19. Moody's, APAC Data Centres: Dispersed growth, unique challenges report, 2025. Applied an exchange rate of 0.67 AUD/USD
20. Cushman & Wakefield, Data Centre Development Cost Guide, 2025. Applied an exchange rate of 0.67 AUD/USD.
21. Mandala, Empowering Australia's Digital Future, 2024
22. AirTrunk, MEL2 media announcement, 2025
23. CBRE, Data Centre growth has economic ripple effects article, 2024
24. BloombergNEF, 1H 2026 Corporate Energy Market Outlook, 2026
25. Mandala, Data Centres as Enabling Infrastructure, 2025
26. Quinbrook, Supernode BESS Project information, 2025

1.2. Data centres in Victoria

1.2.1. A hub for data centre development

Victoria is rapidly emerging as Australia's preferred location for hyperscale data centre development, with nearly three-quarters of new supply under construction in Victoria, Australia.[27] This growth has been concentrated predominantly in Melbourne, where:

- total data centre load, inclusive of projects in early-stage development, has tripled over the past year to 4.7 GW (as at Q2 2025)[28]
- live IT capacity reached 337 MW in 2025, representing a 25% increase from 2024[29]
- enterprise data centre development is growing at 45% compound annual growth rate, exceeding that of any other city globally.[30,31]

Melbourne's attractiveness as a hyperscale destination is due to strong development fundamentals, including large and accessible land parcels, timely and reliable grid connection, access to a high capacity 500 kV transmission backbone, relatively streamlined planning approvals, strong fibre connectivity to the Asia-Pacific region and a growing skilled workforce. Collectively, these characteristics make Melbourne well suited to hyperscale development.

Demand growth is being driven overwhelmingly by AI workloads. In the first half of 2025, AI accounted for approximately 95% of co-location take up in Melbourne.[32] This city now hosts all four major US cloud providers – Amazon, Microsoft, Google and Oracle – whose long-term commitments provide anchor tenancy for new facilities and continue to attract further investment.[33]

In November 2025, the Victorian Government made commitments towards a Sustainable Data Centre Action Plan with a view to securing up to $25 billion in capital expenditure.[34]

Looking ahead, AEMO's 2025 forecast indicates Victoria's share of data centre demand in the NEM is expected to increase from around 25% today to 33% by 2030 and over 40% in the longer term.[35]

Most of this growth is expected to come from new large hyperscale developments connecting directly to the Victorian transmission network, with the balance coming from smaller, distribution connected facilities. By contrast, New South Wales remains the most mature Australian market, largely driven by its existing co-location data centre base.

1.2.2. Pathways to grid connection

The NEM has a structured grid connection process that proponents and network service providers must follow when connecting or altering a plant (e.g. large-scale generation, storage or data centre facilities). This approach is similar in other jurisdictions.

The connection process is regulated via the National Electricity Rules (the Rules) and includes requirements to submit specific information, respond within set timeframes, pass technical performance, study and model requirements and abide by various contractual principles.

New projects must receive grid connection approval before they can begin generating or consuming electricity. The process is designed to enable the timely connection of a new plant while maintaining network reliability, security and safety.

Under the Rules, data centre proponents can apply to connect anywhere on the high voltage network (typically 66kV and above).[36] In Victoria, there are two primary pathways:

1) A distribution connection application with approval from one of the five distribution network service providers licenced to serve customers within their geographical areas. In Victoria, data centre projects typically seek a 22kV or 66kV connection at a distribution zone substation.[37]

2) A transmission connection application with approval from VicGrid (previously AEMO). Under Victoria's contestable model, a data centre proponent can nominate a declared transmission service operator (DTSO) such as AusNet's unregulated business or another third party to build, own, operate and maintain contestable elements of the physical connection. Non-contestable elements of the connection (e.g. cut-ins to the existing network) are provided by the incumbent provider (typically AusNet's regulated business).[38] Data centre projects typically seek a 66kV or 220kV connection at a transmission terminal station. Some hyperscale projects are exploring a 500kV connection.

In some cases, upgrades to the shared transmission network are required to facilitate the connection of a data centre at transmission or distribution level (e.g., new transformers, bus extensions, upgrades to communications or protection systems with an existing station, or an entirely new station).

A simplified overview of the Victorian transmission connections process for connecting data centres, including roles and responsibilities of various parties is provided in **Figure 5**. We note AEMO's Onboarding and Connections team plays an advisory role for all connections in the NEM across transmission and distribution networks to assure the stable and secure performance of the power system. This includes assessing and approving technical performance standards, models and commissioning activities. It is also responsible for plant registration.

Further information on Victoria's network service provider (NSP) roles and responsibilities is in Appendix C.4.

27. M3 Property, Data Centre Growth in Australia Research Report, 2024
28. Knight Frank, Data Centres The Asia Pacific Report, 2025
29. Ibid.
30. Equinix, Global Interconnection Index, 2024
31. See Section 2.2 for further information on different types of data centres.
32. Knight Frank, Data Centres The Asia Pacific Report, 2025
33. Ibid.
34. Victorian Premier, Putting people first in a future with AI Media Release, 2025
35. AEMO, 2025 Inputs, Assumptions and Scenarios Report, July 2025
36. Note VicGrid is in the process of introducing the Victorian Access Regime which are a set of requirements for renewable energy and storage projects seeking access and connection to Victoria's transmission system. These requirements are not expected to apply to load connections such as data centres.
37. Note joint planning requirements typically require VicGrid to consider the impact of distribution connection on the transmission system.
38. Note Victoria is the only jurisdiction in the NEM where TNSP functions are split between itself as the planner-procurer and third-party service providers that own or operate shared network and connection assets. Further information is available on VicGrid's website.

Stages	Pre-feasability (optional)	Technical enquiry	Pre-application	Application and offer	Contracts agreed	Construction	Connection completion	Operations and maintenance
Objectives	Give an early indication of ability to connect in location proposed and understand constraints for the project	Give technical information to help applicant prepare a comprehensive connection application	Optional TNSP services to assist Developers with technical aspects of a future connection application	Submit formal application and request TNSP and AEMO to undertake due diligence to provide an offer to connect	Develop a formal offer to connect based on AEMO's functional specifications (PCRs and PFRs)	Complete construction of all connection works and system models used to support commissioning	Energise and commission connection; and confirm as-built assets meet functional specifications	Operate and control the assets on an ongoing basis and ensure they remain in operable condition
Key actions	**Customer asks VicGrid for process, timeline and technical info**	**Customer submits official connection enquiry**	**Customer requests additional advice from VicGrid**	**Customer submits connection application**	**VicGrid provides formal offer and contract Agreements to customer**	**Customer submits system models and commissioning plan**	**Customer completes commissioning and as-built drawings and minor outstanding items**	**AusNet Tx does O&M for non-contestable assets**
	VicGrid provides this information to the customer	**VicGrid responds to the enquiry**	**VicGrid provides advice**	**VicGrid asks AusNet to create an offer**				
	AusNet Tx may support VicGrid by providing network information			**AusNet Tx scopes and estimates non-contestable work**	**AusNet Tx assists negotiation and populates contract docs**	**AusNet Tx does non-contestable construction works**	**AusNet Tx supports post-energisation activities**	**Nominated DTSO does O&M for contestable assets**
	Customer will begin seeking a Declared Transmission System Operator (DTSO) to delvier the conestable works e.g. build connections asset			**DTSOs will provide offers for contestable work to the customer – who nominates one**		**Nominated DTSO constructs contestable works**	**Nominated DTSO may assist customer**	

Action owner — AusNet Tx* | DTSO | VicGrid | Data Centre

*AusNet Tx refers to AusNet's regulated transmission business responsible for non-contestable connection works to its existing network

Further information on Victoria's network service provider (NSP) roles and responsibilities is in Appendix C.4.

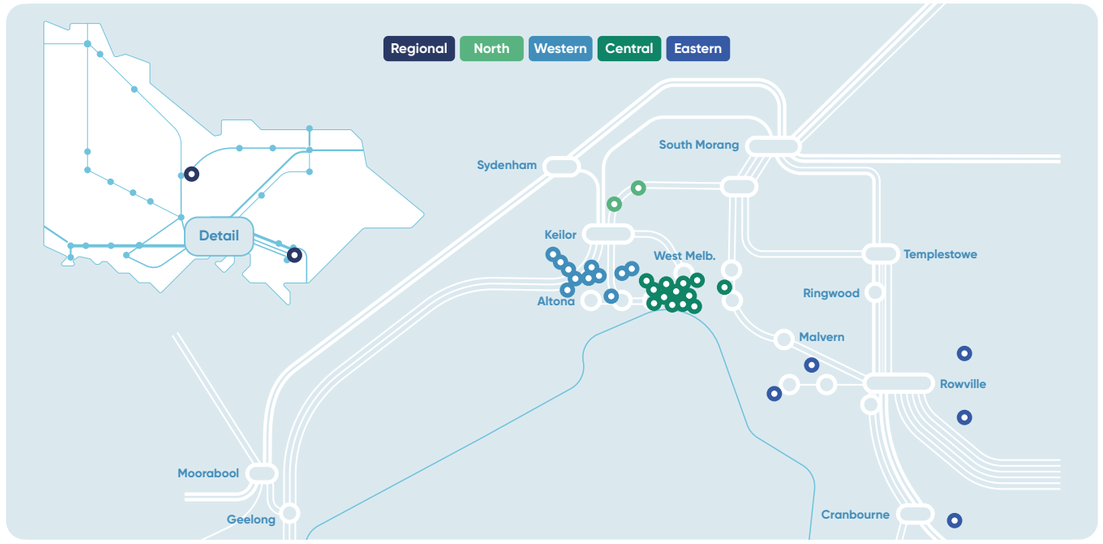
▲ **Figure 5:** Overview of Victorian transmission connections process[39]

39. Note AEMO has an advisory role for transmission and distribution connections across all NEM jurisdictions and works closely with both the proponent and NSP throughout the process.

1.2.3. Development to date

The majority of existing data centre facilities in Victoria are clustered in and around metropolitan Melbourne.[40] These zones are located within 75 kms of each other and offer low latency fibre connectivity, close customer proximity, ready access to power and water infrastructure, skilled labour and established supply chains. More limited development has occurred in the south eastern and outer northern suburbs.

As shown in **Figure 6** below, most operational data centres are located within industrial precincts that provide suitable land and zoning.



▲ **Figure 6:** Map of operating data centres in Victoria[41]

Western and metropolitan Melbourne also offers several comparative advantages. For example, local government incentives, relatively affordable and geotechnically stable land and a more streamlined state planning and environmental approvals framework than other NEM states. This clustering trend is reflected in engagement patterns, with most data centre enquiries received by AEMO Victorian Planning in 2024–25 concentrated in western and northern metropolitan Melbourne, with fewer enquiries in south eastern locations.[42]

40. Each availability zone offer independent power, cooling and network infrastructure working together to increase the reliability of data centre services and exposure to faults.
41. RenewMap – 21/02/2026
42. AEMO, Victorian Annual Planning Report, 2025.

1.2.4. Known future development

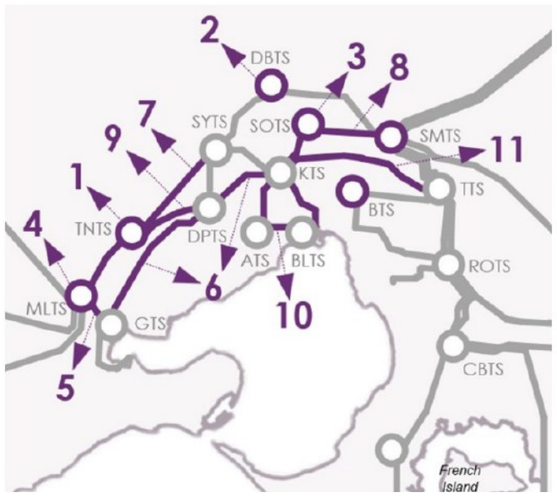
During 2024–25, AEMO Victorian Connections (now VicGrid) received approximately 18 GW of transmission level connection enquiries. Regulatory proposals from Victorian distribution businesses also indicate that several additional gigawatts of data centre demand are seeking distribution level connection, primarily within the Powercor and Jemena networks.

This level of interest is driving the formation of large development clusters at key terminal stations and zone substations across metropolitan Melbourne. In several locations, multiple gigawatts of individual load applications have been submitted to different network service providers in close proximity, often competing for the same limited network capacity.

While not all enquiries are expected to proceed to connection, the volume of advanced data centre development far exceeds current system capacity. This has increased the need to coordinate data centre connections with existing network capability and to identify options for efficiently delivering new capacity alongside other major demand drivers, including economy wide electrification.

Options to enable this growth include developer initiated upgrades to existing terminal stations (such as additional transformers or bays) or establishing new terminal stations to facilitate connections. They also include planner initiated augmentations to the shared transmission network, which are subject to cost benefit assessment. For example, the Southwest Expansion Program outlined in the 2025 Victorian Transmission Plan (VTP) includes the proposed Truganina Terminal Station and upgrades to the surrounding 500/220kV network.

The 2025 Victorian Annual Planning Report (VAPR) provided an initial view of potential augmentation pathways to address projected demand growth, noting that the outlook continues to evolve rapidly (see **Figure 7** below). The scale of required augmentation will depend on how much demand ultimately materialises, with AEMO assessing scenarios at individual terminal stations – or clusters of stations – ranging from approximately 1 GW to 13 GW.



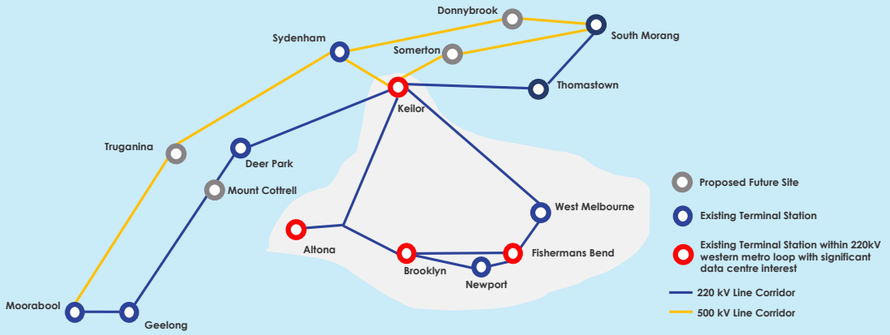
#	Augmentation
1	Establishment of new 500/220 kV terminal station with 2,000-3,000 MVA capacity [A] at Truganina (TNTS) cutting into existing 500 kV lines at an existing future terminal station site
2	Establishment of new 500/220 kV terminal station with 2,000-4,000 MVA capacity [A] at Donnybrook (DBTS) cutting into existing 500 kV lines at an existing future terminal station site
3	Establishment of new 500/220 kV terminal station with 2,000 MVA capacity [A] at Somerton (SOTS) cutting into existing 500 kV lines at an existing future terminal station site
4	Installation of third 1,000 MVA 500/220 kV transformer at Moorabool Terminal Station (MLTS)
5	Construction of third Geelong (GTS) to Moorabool (MLTS) 220 kV line in existing easements
6	Rebuilding existing Geelong (GTS) to Deer Park (DPTS) to Keilor (KTS) 220 kV lines to high capacity 720 MVA
7	Rebuilding existing Moorabool (MLTS) to Sydenham (SYTS) (via Truganina (TNTS) in the future) 500 kV lines to double-circuit
8	Construction of second Keilor (KTS) to South Morang (SMTS) (via Somerton (SOTS) in the future) 500 kV line in existing easement
9	Construction of new 220 kV circuits between Truganina (TNTS) and Deer Park (DPTS) in existing easement
10	Re-arrange and rebuild existing Keilor (KTS) – Altona (ATS) – Brooklyn (BLTS) 220 kV lines into double-circuit Altona (ATS) – Keilor (KTS) – Brooklyn (BLTS) 220 kV circuits
11	Rebuild existing Keilor (KTS) to Thomastown (TTS) 220 kV lines to high capacity 720 MVA

▲ **Figure 7:** Map of operating data centres in Victoria

The following Victorian case studies showcase the speed and complexity of coordinating data centre development with network capacity.

Case study 1: 220kV Western Metropolitan Loop

Western metropolitan Melbourne has been a hotspot for data centre development. To date, existing and proposed data centres are primarily clustered around terminal stations in the 220kV loop from Altona to Brooklyn to Fisherman's Bend and ultimately fed out of Keilor Terminal Station (see **Figure 8** below).



▲ **Figure 8:** A typical data centre components and interconnection

The latest forecasts suggest there is at least 2.5 GW of data centres seeking connection to the 220kV loop via the distribution network alone.[43] AusNet's contestable business is observing further interest at transmission level, bringing the total pipeline closer to 10 GW. Most of this load is seeking connection between now and 2030 and range from 60-500 MW per facility. Some development is already complete, including Victoria's first transmission connected data centre – a 145 MW facility at Brooklyn Terminal Station, commissioned in 2024.

The size and speed of connection interest far exceed the existing western metropolitan loop capacity and timeframes for planning network upgrades. Further, some 220kV stations are nearly full – with limited connection bays or transformation capacity available. This has created a race to secure the remaining capacity, with advanced data centre projects connecting at transmission and distribution level in direct competition with each other. This is exacerbated by developments crowding in areas already constrained.

The future development of the 220kV western metro loop requires careful consideration and coordination. Urban land constraints mean there are limited available corridors to build new circuits to upgrade the existing network. Further development also has the potential to 'crowd out' future electrification growth for other non-data centre customers, or drive constraints that require upgrades to adjacent 220kV and 500kV corridors.

Some consideration is being given to allow aggregate load to exceed available network capacity given the diversity of load profiles and potential for data centres to switch over to back up systems post contingency. In this scenario, a trade-off is required between maximising network utilisation ahead of network expansion and managing reliability risks for all customers connected to the network.

Key takeaway:

Data centre projects connecting to the 220kV metro network are in a race to access the remaining capacity and bays, which are also needed for future electrification load growth. If aggregate load is allowed to exceed available network capacity ahead of network expansion, power system operators will have to carefully consider how best to maintain customer reliability post-contingency. This includes the reliability for non-data centre customers, who typically do not have capability to disconnect from the grid and transfer to back up power systems. We consider this further in Section 6.2.3.

Case study 2: Future Truganina Terminal Station

Truganina is a future 500kV terminal station cutting into the existing Moorabool to Sydenham 500kV lines. The site is recognised in the 2025 VTP as the future gateway into western metropolitan Melbourne and due to be in-service by 2033. When delivered, the terminal station will help reduce the load on the Sydenham to Keilor 500kV lines during high generation and unlock capacity from Victorian Renewable Energy Zones (REZs). It also creates opportunities to expand and reinforce the 220kV network (and subsequently local distribution network).

Truganina Terminal Station is also a highly prospective hub for hyperscale data centre development. AusNet's contestable connections business is aware of multiple hyperscale operators seeking transmission connection at the site, with some projects proposing 'ultimate' capacity exceeding 500MW each.

Connecting data centres to the 500kV network offer a simpler and faster development pathway as it offers access to greater capacity, reliability and redundancy that allows for the expansion of data centres over time. There are multiple large undeveloped sites around the 500kV network. These sites are often located in industrial areas with less space restrictions and are typically better placed to connect larger hyperscale facilities.

Key takeaway:

New terminal stations on or near the 500kV system are expected to offer a simpler and faster development pathway for data centres to connect due to the strong backbone offering the most secure connection and significantly greater hosting capacity, along with improved land availability.

43. Victorian Electricity Distribution Businesses, 2025 Transmission Connection Planning Report, 2025

1.3. Connection challenges for data centre developers and equipment manufacturers

Securing grid connection is a critical milestone that underpins the viability of a developer's data centre project. Without an offer to connect, a developer is limited in its ability to demonstrate to its board, financiers and customer(s) that the commissioned IT capacity will be operational on time and at the size expected.

Discussions with Bespoke Energy and AusNet's unregulated business suggest developers and their original equipment manufacturers (OEMs) are currently finding an unclear and often inconsistent landscape when attempting to connect large data centres to the NEM. Developers reported these challenges stem from regulatory ambiguity, inconsistent connection processes and a lack of certainty with emerging and evolving technical requirements.

Some known pain-points for data centre developers in the grid connection process:

- **Lack of clearly defined performance, modelling and study requirements**

  Some developers and OEMs have raised concern with the lack of clear and consistent technical benchmarks specified by network service providers. Fault ride through requirements have proven to be particularly problematic. While certain fault ride-through behaviours are often cited as necessary, the underlying parameters are not always disclosed or expressed in a way that readily translates into equipment design. This creates a "chicken and egg" problem – developers are willing to comply but cannot design compliant systems without definitive standards.

  For OEMs, uncertainty around modelling requirements presents a significant barrier. Although some manufacturers have already developed dynamic root mean square (RMS) and electromagnetic transient (EMT) models aligned with the AEMO Power System Model Guidelines, it remains unclear if and how these guidelines apply to data centre equipment. Without explicit guidance, OEMs face ambiguity about compliance obligations, increasing the risk of delays, resource misalignment and added project cost.

- **Inconsistent processes across the NEM for large data centre connections**

  Data centre connection requirements vary depending on the network. In Victoria, transmission-connected data centres are currently subject to more comprehensive performance, modelling and study requirements than distribution-connected facilities, even if those facilities are of a similar size and nature. This lack of consistency risks concentrating data centre development in particular locations to avoid the more stringent requirements, with potential system-wide impacts. It also creates uncertainty for developers seeking to design repeatable connection solutions and manage grid approval risk.

  Data centres require a certain scale to be economically viable. However, some developers choose to proceed with projects at a smaller scale, with plans to repeatedly retrofit and expand later to meet their ultimate desired data centre power consumption size. In this way, they are avoiding triggering any additional scrutiny on their power system performance. This creates a paradox: staying small may be unsustainable, but growing too quickly triggers burdensome compliance hurdles, which may not even be defined yet.

- **Shifting connection requirements**

  In some cases, developers are at risk of disruption due to significant changes to connection requirements mid-project (often after substantial investment has already been made). Reported examples include changes to controller settings to meet new technical requirements, or requirements for highly detailed power system models where there were previously no requirements. Late-stage changes can result in costly redesigns, project delays and strained relationships between developers and network service providers.

Many of these connection challenges can be explained by the fact that the NER currently has limited technical requirements for inverter-based load connections. Substantial work is underway by the AEMO and AEMC to define and implement technical performance requirements to facilitate the anticipated growth of data centres, and the flow on effects for modelling requirements (see Appendix B for further information).

From our lens as a network operator, a consistent, transparent and predictable grid connection process is critical to keeping the network secure. As inverter-based loads become a greater proportion of the overall system load, power system risks grow. If not subject to fit for purpose connection performance and modelling requirements, overtime, AEMO and system operators may have to rely on operational limitations to maintain system stability and security.

1.4. Building an electricity system to enable data centres

Jurisdictions best placed to unlock the benefits of data centre growth are those with the right supporting infrastructure, systems and processes to deliver timely access to energy, water and communication assets.

'Power infrastructure' is consistently cited by investors as the biggest challenge to data centre development.[44] The International Energy Agency expects grid constraints to delay around 20% of the global data centre capacity planned for construction by 2030.[45] Like many other countries, Australia is at an early stage of building its electricity system to support data centres loads, which is one of many drivers of the broader energy transition.

Positioning Australia as a globally competitive hub for digital infrastructure requires progress across several areas:

- **Improving demand forecasts to better understand the volume and timing of data centre connection interest, including identifying credible projects from speculative enquiries**

  Network service providers can get multiple applications for the same IT load and different forecasting methods can be used for different purposes. A validated aggregate forecast at the terminal station and regional level enables parties to plan with confidence and make efficient long-term decisions in the interests of electricity consumers.

- **Building electricity infrastructure to address network, generation and essential system service limits at the lowest cost to consumers**

  Data centres are only one of several drivers of electricity system investment related to the energy transition. The scale and timing of the investment depends on a range of macro factors, including economic growth, electrification, coal retirements, technological change and policy settings, as well as site-specific factors such as energy efficiency, reliability requirements, demand flexibility and terminal station and urban land constraints. Together, these considerations need coordinated strategic planning that optimises outcomes across the broader energy transition.

- **Understanding and accommodating large-scale data centres**

  The operational characteristics of large-scale data centres differ from those of the traditional loads that power systems were designed to serve.[46] As a result, jurisdictions globally are developing a clearer understanding of how data centres interact with the power system and defining the requirements needed to accommodate them while maintaining power system integrity. These requirements primarily relate to system security, both when connecting and operating data centres (including performance, modelling and study obligations) and when managing the shared network as data centres come to represent a significant proportion of system load.

Across the NEM, efforts are underway to safely integrate data centres while maintaining power system integrity and minimising power system impacts.

44. CBRE, Global Data Centre Investor Intentions Survey, 2025
45. International Energy Agency, Energy and AI Work Energy Outlook Special Report, 2025. The IEA examined current congestion levels, grid policies and connection timelines in various jurisdictions to develop different scenarios for the possible number of data centres that may be delayed.
46. North American Electric Reliability Corporation, Large Load Task Force White Paper - Characteristics and risks of emerging large loads, 2025

2 Defining data centres

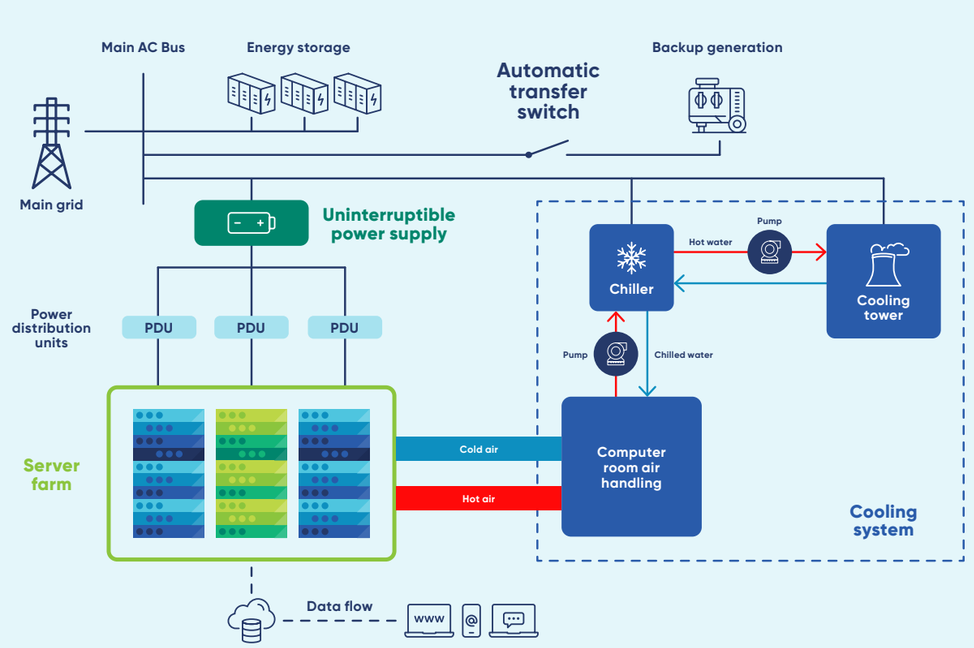
Key messages

- From a grid interaction perspective, a data centre is best represented as two interacting elements:
  a) **Server Farm**, which sets the MW demand profile
  b) **Uninterruptible Power Supply**, which determines how a data centre responds to a disturbance, such as an outage or over- or under-voltage event. Cooling and ancillaries are usually secondary and can often be omitted from first-pass grid impact discussions.
- Physical form, ownership, functional role and Uptime Tier are dimensions for data centre classification and practical screening measures for grid impact. Regarding the latter, these dimensions indicate how big the load is, how quickly it can change, how controllable it is, how much load is likely to drop off (power lost) during grid disturbances and how it returns.

This chapter provides an overview of the key components of data centres that affect grid interactions (Section 2.1) and how they are classified (Section 2.2), as context for the deeper analysis of the data centre and power system interactions in subsequent chapters.

2.1. Key components in data centres

Figure 9 shows a simple data centre layout, key equipment and the interconnection between them.



▲ **Figure 9:** A typical data centre components and interconnection[47]

47. Journal of IEEE transactions on automation science and engineering, A complete model for modular simulation of data centre power load, 2017

Three key systems outlined in **Figure 9** can affect how data centres interact with the grid:

- **The server farm** is the backbone of the data centre, comprising large numbers of individual servers that perform data storage, processing, hosting and other activities. It determines the primary power demand drawn from the grid during normal operation, setting the "MW demand profile" for the data centre.
- **The uninterruptible power supply (UPS)** determines when the server load needs to disconnect from the grid to maintain supply and manages the transition to stored energy (for example in a battery). The UPS determines how a data centre responds to a disturbance, such as an outage or over- or under-voltage event.
- **The cooling system and ancillary loads** support data centre operation but typically represent only a small proportion of total power demand and connection capacity. As a result, they have a limited influence on overall power system performance and can be reasonably excluded from detailed operational analysis.

Assessments of a data centre's impact on the power system can be focused on the two components that materially affect grid behaviour: the server farm and the UPS.

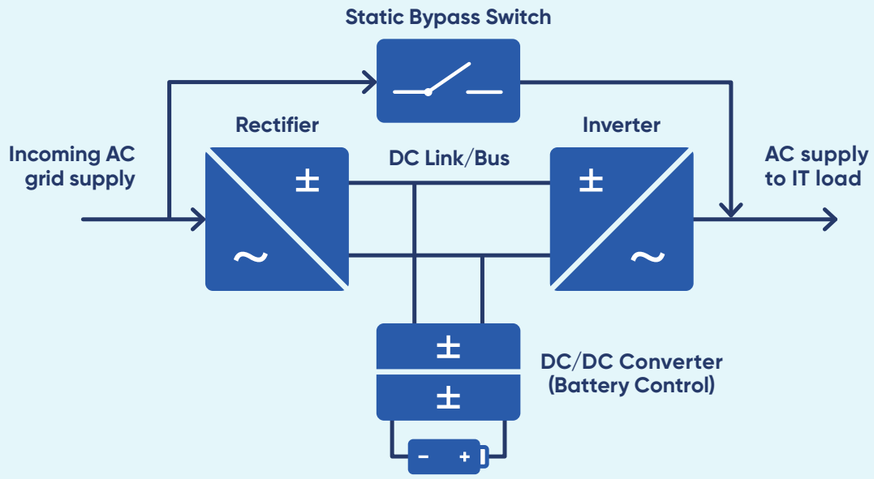
2.1.1. Uninterruptible Power Supply (UPS)

The UPS has a strong influence on how grid-side disturbances are handled and the net impact on the power system. It is introduced here in preparation for discussions in later sections.

Its control logic and response characteristics, such as fault ride-through capability, can significantly affect power system performance, particularly when data centres are large (either individually or in aggregate).

By determining when and how to disconnect from or reconnect to the grid, the UPS plays a pivotal role in either mitigating or amplifying the effects experienced by the power system. Its behaviour must be well understood and coordinated with broader system protection and operational standards so that its actions support, rather than compromise, overall grid resilience.

Figure 10 shows a double-conversion UPS, which is a typical structure used in many data centres. The rectifier continuously converts incoming AC to DC for the inverter and charges the battery; the inverter continuously synthesises a clean, regulated AC for the IT load. Because AC to DC to AC conversion is continuous, the IT load is isolated from voltage and frequency disturbances on the grid.



▲ **Figure 10:** Simplified online double-conversion UPS architecture. AC input is first rectified to DC (charging the battery bank), then an inverter creates a clean AC output for the IT load. A static bypass provides redundancy

During grid disturbances or outages, the inverter seamlessly draws from the battery/DC link so there is no interruption and a static bypass provides a redundant AC path for overload/fault scenarios. Modules are commonly three-phase and can be paralleled to multi-megawatt scales, with an optional DC/DC stage between battery and DC link for tighter control.

Further information about the UPS components and operation are available in Appendix C.1.

2.2. Data centre classifications

Data centres can be classified by physical form, ownership model, functional role and Uptime Tier. Each classification highlights different characteristics that are relevant to how these facilities interact with the power grid and the profile of the power drawn from the grid.

At a high level, these differences can be summarised as:

- **Physical form** determines scale, siting and the balance of IT versus cooling loads. Hyperscale campuses present very large, steady underlying loads with a layer of loading on top with the potential for rapid power consumption variations, while edge and modular or containerised deployments appear as many small nonlinear loads dispersed across feeders.
- **Ownership** changes who controls workload scheduling and the backup strategy and therefore the practical demand-response envelope.
- **Functional role** workloads drive the dynamic demand of power from the grid. For example, AI training exhibits large, coincident power swings (from seconds to minutes), while content delivery may be stable over seconds to minutes but exhibit very large increases in demand following a diurnal cycle.
- **Uptime Tiers I–IV** determine redundancy and acceptable downtime for data centres.

Table 2 below summarises common data centre types along these dimensions. Comparative tables are included in Appendix C.2 to summarise differences on power system performance, grid connection requirements and grid connection performance.

Physical form	Ownership model	Functional role	Uptime tier
Enterprise (on premises)	Enterprise (on premises)	AI training or inference	Tier I Single path, No redundant components
Edge/Micro	Colocation (multi-tenant data centre (MTDC))	High-performance computing (HPC) / simulation / rendering	Tier II Single path, N+1 (one spare) components
Modular/ Containerised	Cloud / hyperscaler	Disaster recovery (DR)	Tier III Concurrent maintainability (dual A/B paths; N+1)
		Telecom / network	Tier IV Fault-tolerant, 2N (two independent full-capacity paths)
		Content Delivery Network (CDN) / edge cache	
		Price-sensitive compute	

▲ **Table 2:** Classification type summary

3 Data centre behaviour

Key messages

- Data centres are a new 'non-uniform' inverter-based load. They can exhibit fast MW variability, uncertain ramping profiles during normal operation and are sensitive to disturbance risks, which makes them materially different to the traditional large industrial loads that power systems were designed to support. Some data centres are also large enough to change system operating conditions and when clustered, can turn localised events into material system events.
- Compared to traditional large industrial loads, data centres can exhibit faster and more coincident demand changes, including seconds-scale swings and step-like variations that can become system-visible when many racks or halls align. Power system and associated planning and operational frameworks across the globe are not designed to manage some of these data centre behaviours.
- Leading data centre operators are establishing good practice in how they specify, design and operate their electrical, control and cooling systems and how they orchestrate workloads and power caps. This includes starting to implement features like workload and rack-level controls, including ramp-up caps ("gentle start"), smoothing of short spikes ("fill valleys and shave peaks"), power capping, task staggering and controlled ramp-down/holds ("gentle stop"). These practices are emerging, not universal.
- International experience shows repeatable system-level patterns, coherent behaviour across campuses, sensitivity to sequences of disturbances (including auto-reclose shots) and some cases of control-driven oscillations above certain loading thresholds. Mitigation typically involving firmware updates, retuning and temporary MW caps while fixes are validated.
- Grid events should be assessed end-to-end, meaning both the conditions that trigger transfer to backup and the post-event reconnection and recovery profile, since recovery can create a second contingency if large load blocks return too quickly.

Chapter 3 outlines how data centres are behaving and interacting with the power system:

- How data centres differ from other large loads (Section 3.1).
- The typical load profile and ramping behaviours of data centres (Section 3.2).
- Complexities introduced when data centres are co-located with energy generation and storage facilities (Section 3.3).
- International examples of challenges integrating data centres into power systems and lessons to learn from (Section 3.4).

3.1. How data centres differ from other large loads

Data centre technical performance is primarily a function of the services they provide and the requirements of their customers. For example, a data centre that only hosts databases, email servers and financial transaction systems would likely have a constant load with minimal fluctuation. Data centres primarily for cloud computing have variable loads and seasonal spikes. Data centres hosting AI training, gaming or media streaming events have computationally intensive "bursts", with large variations in power and cooling requirements. Read more about load profiles in section 3.2.

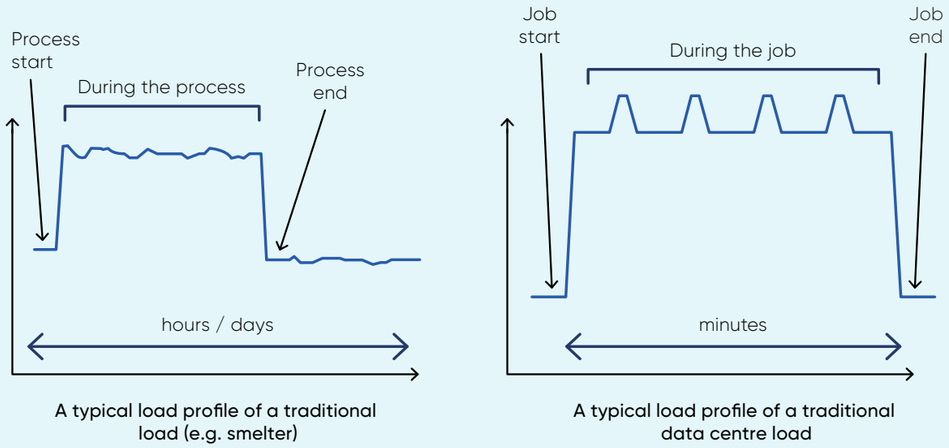
The practical challenge is that the power system and associated planning and operational frameworks were developed to support traditional large loads and therefore do not fully anticipate the speed, coincidence and variability of modern data centre demand.

Table 3 provides a summary of key differences in load profiles and event response behaviours between data centres and other large industrial loads, such as smelters, refineries, electrolysers and EV charging stations.

Aspect	Data centres (DC)	Other large loads (examples)
Fault / disturbance response	IT is buffered by UPS; many sites transfer to backup on ordinary dips/successive recloses; behaviour can be coherent across halls.	Smelters, refineries, big motors usually ride through (ignore) short dips and continue drawing energy from the grid.
Seconds-scale variability	Coincident 0.5–5 s power swings from compute cycles; visible in frequency and voltage metrics.	Electrolysers/EV hubs can be fast but are typically less coincident at a seconds scale.
Reconnection / reload	Risk of large, fast reloads after islanding/UPS operation if not staged.	Many industrials have slower, procedural restarts.
Ramp rates (dp/dt)	Orchestrators/power-capping can change load very quickly; cooling adds steps.	Many industrials ramp slower; some are rate-limited by process control.
Geographic clustering	Hyperscale campuses are clustered on a few corridors where a single fault can result in a significant MW loss.	Others loads are often more dispersed.
Grid frequency response	UPS of data centres may be capable of operating across extremely broad frequency ranges (e.g., from 40 Hz to 70 Hz) and will not disconnect or alter energy draw even if the grid experiences heavy frequency excursions.	Large loads in the system may be tied to a form of remedial action scheme whereby their grid-supplied energy consumption may be altered or curtailed entirely depending on the frequency of the local grid. Power-electronic loads, for example VFD-driven motors and rectifier-fed processes are decoupled from grid frequency and will not reduce power on their own; any relief requires control logic or shedding. Only directly grid-connected motors without drives exhibit some natural load relief as frequency and voltage fall, and even then process constraints and protection often limit the effect.
Price Driven	Depending on the energy contracting arrangement and client needs, some types of data centres may have sufficient flexibility to schedule non-critical workloads at periods of low electricity prices only, making their load consumption sensitive to the market spot price.	Large loads usually have long-term off-market bilateral supply contracts which provides pricing certainty to both the load and supplier, meaning they are insensitive to electricity spot market prices.

▲ **Table 3:** Data centres versus other loads

Figure 11 below compares the typical load profile for traditional loads (such as smelters) with those of data centres.



▲ **Figure 11:** A typical load profile for traditional load and data centre load

3.2. Typical data centre load profiles and ramping behaviours

The short-term power-draw impact of data centres (ramping behaviour) can have a large impact on grid operations. Sudden, large changes in demand at scale are routine for data centres. Without preventative mechanisms, this behaviour has the potential to impact network asset lifetimes, trigger grid-scale control schemes and erode headroom on frequency control equipment and markets. These scenarios are accounted for in system planning but are designed to be triggered infrequently, not in a business-as-usual operating environment.

Large inverter-based loads can ramp demand bidirectionally at rates of hundreds of megawatts in seconds, which impacts the grid even when the site is operating normally - especially when multiple large loads are geographically concentrated.[48]

Technological advancements mean this is a rapidly evolving space and we anticipate that ramping behaviours will become less peaky over time. Power system operators and planners are required to make power system integrity decisions based on current and worst-case data and experiences, meaning that managing load performance to minimise adverse system impacts is prioritised.[49]

48. NERC Large Loads Task Force (2025), Characteristics and Risks of Emerging Large Loads, July 2025.
49. Network service providers must comply with power system performance and quality of supply standards when connecting data centres to a transmission or distribution network. Failure to do so is classified as a tier 1 civil penalty.

3.2.1. Examples of data centre load profiles

The following observations of data centre load profiles and ramping behaviours are based on data centre customer descriptions of application-specific tasks and published data centre workload profiles, which we assume correlates with power consumption. There are many additional application-specific tasks and data centre functions, but the following are examples to:

- demonstrate the variety and scale of data centre behaviours today
- fill a gap in research on short-term power usage trends, which are less understood than long-term trends due to the commercial sensitivity of the information.

3.2.1.1. Artificial intelligence-based loads

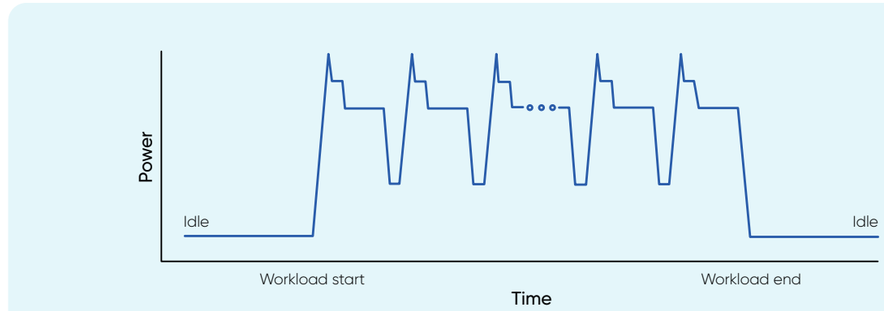
AI-based loads have the greatest ramping behaviours. **Figure 12** below shows a typical AI-compute power trace:

a) a rapid ramp-up from idle to high load

b) coincident (in-step) seconds-scale swings (≈0.5 to 5 s) during the run

c) a rapid ramp-down at job end.

When many racks or halls run the same job, the small per-rack swings line up and present as MW-scale pulses at a cluster level. The amplitude and cadence of the swings depend on the workload phase and scheduler and the cooling plant can superimpose slower step changes on top of the fast cycling.



▲ **Figure 12:** Coincident AI-workload power profile (fast ramp-up, repeated spikes, fast ramp-down). Source: Confidential

Start-stop, rapid-step pulsating power draws are required for AI computers today. Such a profile can challenge the power system when the magnitude of the pulses reach single digit MWs at the distribution network level or extend into tens of MWs at transmission level.

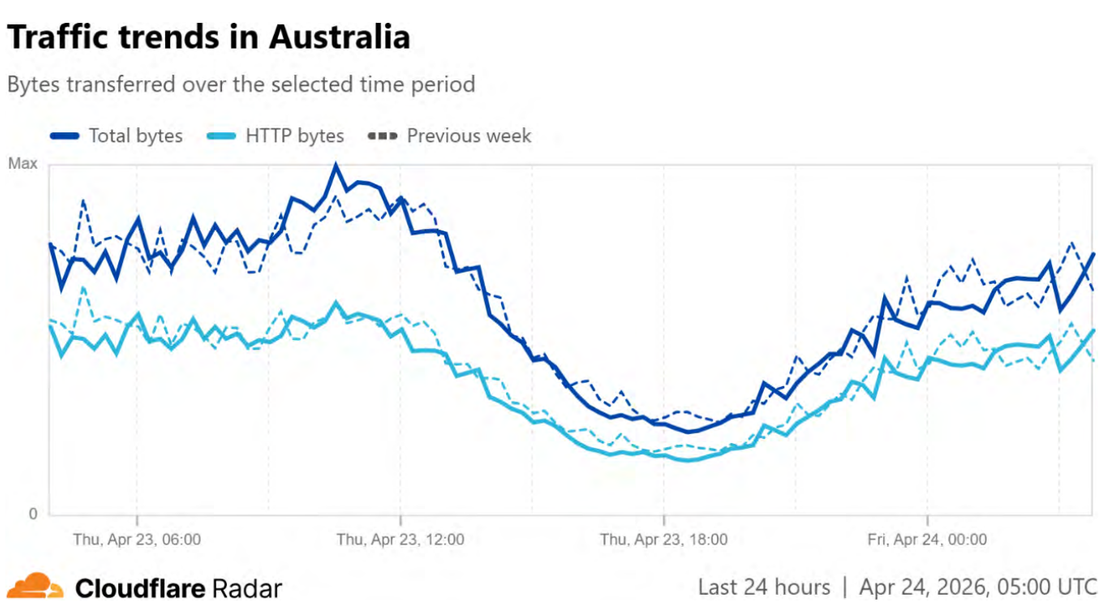
Appearing as a forced oscillation on the network, such large, rapid power swings have the potential to unduly trigger frequency control mechanisms, cause power quality standards to be breached (e.g. voltage flicker), or even excite instabilities in the power system, if the pulses align with unstable frequencies of the power system and its components.

Depending on the timescale of the power swings, this behaviour can increase the frequency of mechanical and discrete control actions, such as tap changer operations and switched shunt capacitor or reactor switching, with implications for asset wear and service life. These impacts scale with data centre size.

Advancements in technology or operations that moderate spikes and ramp-up and ramp-down rates are being welcomed by grid operators. Section 3.2.2 outlines emerging work in this space.

3.2.1.2. Content Delivery Network-based loads

Content Delivery Network (CDN) based server loads follow the daily rhythm of internet traffic. **Figure 13** shows this profile with traffic requests from one of the world's largest content providers, Cloudflare, over 24 hours.[50] Traffic requests remain steady throughout the day, peak in the evening at around 8:30 pm AEST (10:30 am UTC), and then decline to early-morning lows at about 4:00 am AEST (6:00 pm UTC). It is reasonable to assume that the number of traffic requests correlate to the required power consumption, hence the diurnal profile of CDN power consumption will be similar to that shown below.



▲ **Figure 13:** Cloudflare internet traffic for Australia.[51] Source: radar.cloudflare.com/au

The power demand of data centres providing CDN services is largely dictated by business and consumer behaviours, with CDN operators working to meet demand in real-time. There is limited opportunity to change the power consumption profile to make power system operators' jobs easier.

However, there may be opportunities for fast power consumption shaping at a task-level, including the potential for power consumption smoothing through task staggering and participation in grid supporting services such as frequency control. The operational complexities outweigh the potential financial benefits of implementing these activities, so uptake by data centre operators is very low.

3.2.1.3. High performance compute

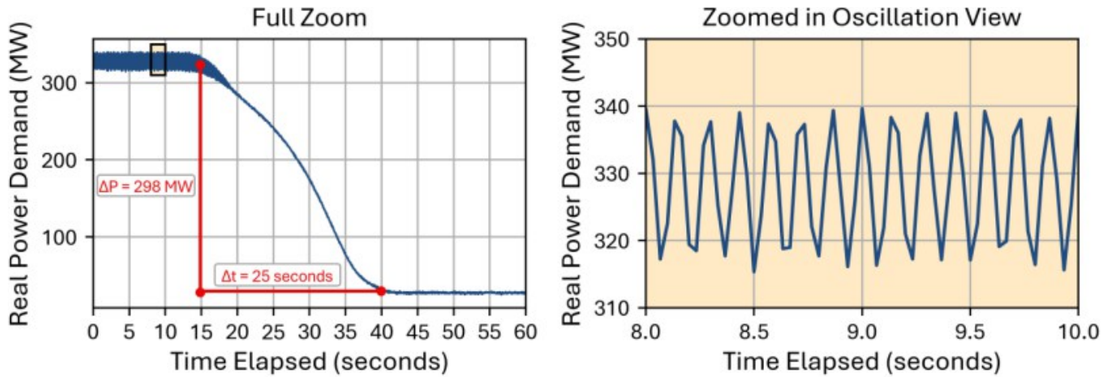
High performance compute (HPC) jobs (such as complex simulations or training AI models) are often batch scheduled and may show step-like power profiles that repeat at iteration or job boundaries. However, because they can be scheduled, there is potential for a solution through smart task staggering and application of workload power caps.

Measured traces on modern GPU clusters indicate that power caps can moderate peaks with limited performance impact.[52] This helps operators smooth MW-scale swings and stay within facility limits during congested periods. Sites typically monitor per-job power and apply caps where the energy-to-solution trade-off is favourable.

50. Individual CDN workload power consumption figures were not available.
51. Cloudflare radar, Australia Overview, 24 April 2026.
52. Acun, F., Zhao, Z., Austin, B., Coskun, A. K., & Wright, N. J. (2024). Analysis of power consumption and GPU power capping for MILC. Boston University & Lawrence Berkeley National Laboratory.

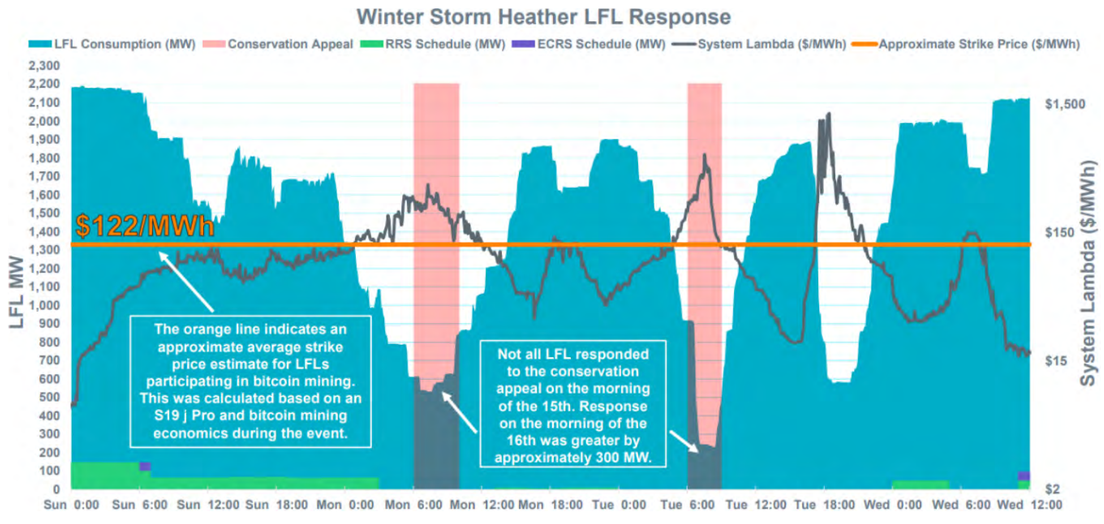
3.2.1.4. Cryptocurrency and price-sensitive loads

Unlike standard data centres, where power draw ramps with customer demand or training cycles, cryptocurrency mining facilities have a greater ability to shift load. They generally run at a steady internal set-point but are programmed to be highly responsive to price. When electricity prices spike or grid conditions tighten, miners can curtail load sharply and then ramp back as prices ease, as shown in **Figure 14**.



▲ **Figure 14:** Cryptocurrency mining facility load oscillation and ramp down (GridLab report).[53] Source: nerc.com

In markets that support controllable loads, scarcity-event curtailment has exceeded 95%, as shown in **Figure 15**. These behaviours create pronounced price-driven profiles that can support the grid, although rapid ramps can stress local feeders if coordination is poor. Planning studies should model curtailment logic, response times and any market ramp-rate limits.



▲ **Figure 15:** Winter storm large load response (NVIDIA Technical Blog).[54] Source: wecc.org

53. GridLab, Large Loads Interim Report, March 2025.
54. NVIDIA, How New GB300 NVL72 Features Provide Steady Power for AI, July 2025.

3.2.2. Advancements in rack-level controls for AI loads

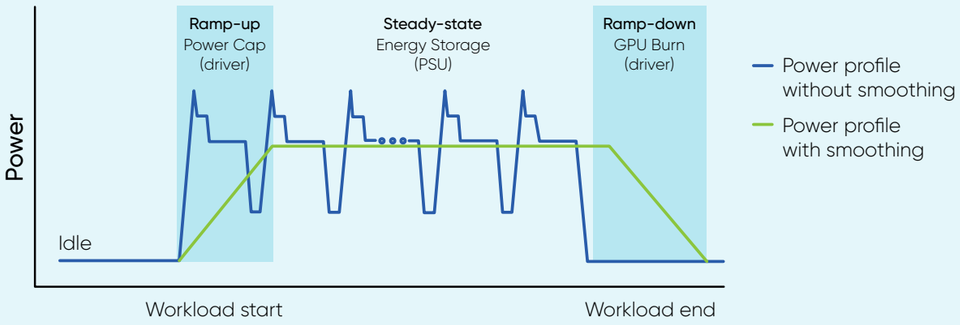
Some data centre proponents are working with OEMs to develop rack-level controls that help smooth data centre load behaviour and address active power variation at the grid side. These controls are available on some new systems but are still emerging technologies and are not universally adopted.

The measures that primarily shape grid-side MW variability and ramp rates during normal operation are outlined in the subsections below. They do not remove the need to address disturbance tolerance and UPS-driven transfer-to-backup behaviours.

3.2.2.1. Gentle start (ramp-up cap)

The rack does not jump to full power when a job starts. Rather, input power rises gradually at a set rate which keeps the rate-of-change of power (dp/dt) within the site envelope. On weaker feeders (circuits), it also helps avoid voltage fluctuations for other customers.

In **Figure 16**, a grey trace reproduces the "raw" AI workload - fast ramp-up and a spiky steady state. Over it, a green "smoothed" trace shows a gentle ramp-up and a flatter steady state. The ramp-up window is highlighted to indicate a power-cap that raises allowable input in steps.

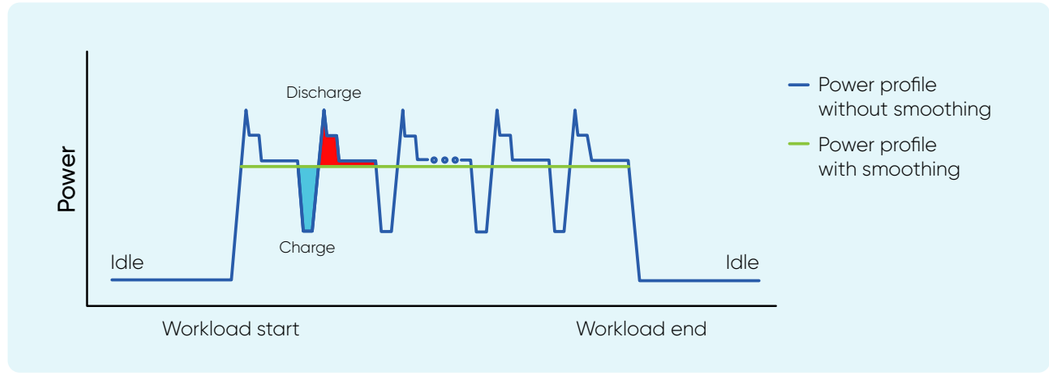


▲ **Figure 16:** Power smoothing overview (ramp-cap at start; steady-state smoothing; burn/controlled ramp-down at end). Source: Confidential

3.2.2.2. Smoothing of short spikes

Even during steady operation, compute loads have short, seconds-to-sub-second variations. The rack's power shelf flattens these at the AC input, so the grid sees a steadier draw while the internal DC to accelerators still cycle.

Using the same workload, **Figure 17** shows troughs where the capacitors charge (in blue) and peaks where they discharge (in red). The result is the flattened green line for rack AC input during steady operation, despite the underlying GPU DC power continuing to cycle. In short, storage "fills valleys and shaves peaks," making the rack look steadier at the grid interface.



▲ **Figure 17:** Energy-storage behaviour in steady state (charge in troughs, discharge on peaks → flatter AC input). Source: Confidential

3.2.2.3. Gentle stop (ramp-down/hold)

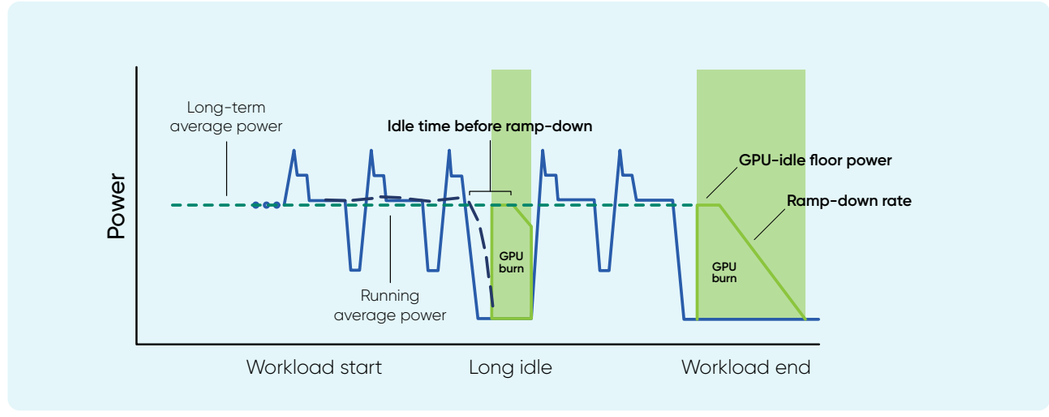
When a job stops, the rack briefly continues to draw at a controlled level before tapering off. This feature avoids a sharp negative rate-of-change of power (dp/dt) that could affect AC frequency and cause the UPS to activate unnecessarily.

Figure 18 shows the power flows a data centre operator can tune at the end of a run:

- active floor (the lowest power while the GPUs are still doing work)
- idle floor (the level they sit at during a short hold)
- length of that hold
- ramp-down rate as power tapers off.

The figure shows a short GPU burn that stops power dropping suddenly, then a smooth glide down.

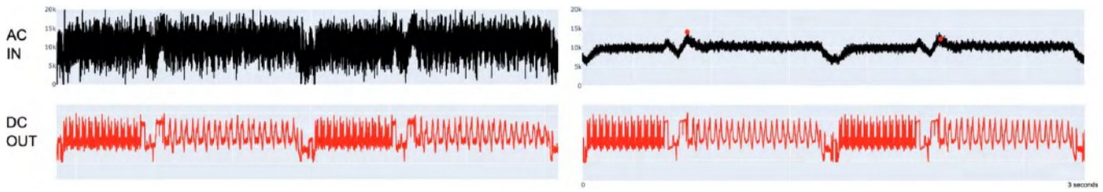
This is not "free" energy and at scale it can impose a sizable operating cost if applied frequently or for long durations, so it should be assessed against other mitigation options on a site-by-site basis. Depending on site design and operating constraints, alternatives or complements may include coordinating job scheduling, power capping and using on-site energy storage (including UPS batteries or a separate BESS) to shape the net power seen at the grid interface.



▲ **Figure 18:** Controlled ramp-down / hold (tuneable idle floor, hold time, ramp-down rate). Source: Confidential

3.2.2.4. Power shelf

The AC power shelf that feeds each rack includes small, fast energy storage (capacitors). It buffers short spikes so the AC input looks smoother. This can be considered as behind-the-meter demand smoothing - it reduces fast spikes but doesn't export power and isn't a UPS. **Figure 19** compares two traces of the same rack under an identical workload, with and without storage. When storage is included, the AC input peak is reduced and the trace is smoother, while the DC output delivered to the accelerators follows the same workload in both cases.



▲ **Figure 19:** Same rack, same workload — AC input/DC output with energy storage (right) vs without (left). Source: Confidential

3.2.2.5. Applying these emerging approaches to commonly encountered scenarios

Table 4 outlines common data centre work scenarios, their generalised impact on the power system and suggested approaches using emerging approaches to avoid excessive impact on the power system.

Scenario	What happens	What the grid sees	What to do
A) Job start	Power climbs from idle to high.	Positive dp/dt (fast rise).	Limit ramp-up in rack (**Figure 16**); stagger starts; site ramp limit at connection point.
B) During the job (periodic steps)	Repeatable bumps every 0.5–5 s.	Flicker-like modulation; small frequency wobble.	Use rack smoothing (**Figure 17**); power-capping; stagger phases.
C) Job end / abort	Power would drop suddenly.	Sharp negative dp/dt (can push frequency up).	Hold + tapered ramp-down in rack (**Figure 18**); follow campus ramp-down policy.
D) Multiple faults	Several short dips can transfer many racks to backup.	Large MW step down, then reconnection swings.	Set demand-side fault ride-through (FRT) requirement accounting for the number of faults.

▲ **Table 4:** Common work events and grid impacts

3.3. Co-location of data centres

Co-locating data centres with energy generation and storage facilities is becoming increasingly attractive to operators, offering cost efficiencies, opportunities for energy arbitrage and enhanced resilience – particularly when zero-cost energy sources such as photovoltaic solar are available. When configured as an "islandable" system behind a single connection point, this approach can also mitigate grid constraints and outage risks.

However, such integration can introduce power system stability challenges. Both data centre UPS systems and inverter-based resources (IBRs) rely heavily on power electronic interfaces, resulting in clusters of fast-acting controllers. Coordinated tuning is required to prevent adverse controller interactions such as oscillatory behaviour that may lead to equipment shutdowns. This risk can be amplified when devices from multiple vendors employ proprietary control schemes not tailored to local conditions or imported from stronger power systems.

Weak external grids can further exacerbate these issues. In such environments, small variations in current may trigger large voltage changes, creating positive feedback loops and destabilising local system dynamics. This challenges conventional assumptions regarding system resistance and stability margins.

Therefore, while co-location may offer commercial and operational benefits, it requires rigorous early-stage planning, detailed modelling and coordinated design to safeguard both local and system-wide reliability.

For example, protection coordination is critical for rapid fault clearance and maintaining operational integrity under both grid-connected or islanded conditions. Regulatory requirements from network service providers and AEMO can also support detailed modelling of system behaviour across diverse operating scenarios. While these requirements increase project complexity, they ultimately contribute to broader grid stability.

In North America, behind-the-meter generation located onsite is increasingly being adopted as a solution to circumvent long grid interconnection queues in the region[55], with natural gas currently the leading generation technology of choice for onsite deployment.[56] For example:

- several of Stargate's planned new AI data centre sites are choosing gas generation to provide both primary and backup power[57,58]
- Sidecat plans to power their data centre operations via an adjacent 200MV natural gas-fired plant behind-the-meter.[59]

This increase in uptake of the behind-the-meter model for the primary powering of data centres in North America may be influenced by rapidly shifting regional regulatory landscapes amid the speed to market race, where natural gas presently holds its advantages as a scalable technology capable of continuous dispatch.

However, despite the potential benefits of behind-the-meter arrangements, grid connection is still the preferred end goal for most data centre developments.[60] This may be due in part to the challenges associated with co-location, including availability of land for co-location, strength of fibre connectivity, security of water supply in regions where co-location is feasible and the viability of large-scale generation resources as a primary power supply.

We welcome and encourage Australian data centre developers to share further evidence on the benefits of co-location. For example, real world case studies of planned or operational data centres that are actively supporting the grid through demand response and flexible load management and participation in ancillary service markets.

55. JLL, North America Data Center Report Year-end 2025, February 2026.
56. Ibid.
57. Stargate is a multi-campus initiative established by a joint venture between Open AI, Oracle and Softbank. It has greater than 7GW of planned collective capacity. See following for further information: OpenAI, OpenAI, Oracle, and SoftBank expand Stargate with five new AI data center sites, September 2025.
58. Office of Representative Jodey Arrington, Oracle Fact Sheet: Stargate Data Centers, September 2025.
59. Sidecat is a Meta-affiliated company with data centre project located in New Albany, Ohio. See following for further information: Ohio Power Siting Board, OPSB approves construction of Licking County natural gas-fired power plant, June 2025.
60. JLL, North America Data Center Report Year-end 2025, February 2026.

3.4. Recent international system incidents involving data centres

3.4.1. Summary of incidents

Data centre involvement in large-scale system disturbances is a growing phenomenon worldwide, where the performance of one or more data centres has had an impact on the power system relative with their collective size. **Table 5** consolidates recorded grid incidents involving large data centres, identifying the root causes and grid impacts.

Date	Area / utility	What happened	Root cause(s)	Grid impact
7 Jan 2022	Ireland – Killpaddoge–Killonan, 220 kV (EirGrid)	A transmission fault on 220 kV circuit caused disconnection of 74 MW of data centre load.	Grid voltage dropped below the level where UPS transfers to back-up supply.	RoCoF of approximately −0.16 Hz/s a frequency trough of around 49.7 Hz.
June 2022	Dominion Energy	A cluster of large data centres experienced approximately 14.7 Hz voltage oscillations in a local 115 kV region.	Limit cycle created by interaction between an unstable internal controller and its limiters in data centre equipment.	Persistent sub-synchronous oscillations.
13 Dec 2022	Ireland – Kellystown–Woodland, 220 kV (EirGrid)	A single-phase fault with a trip–reclose–trip sequence led to a transfer of around 204 MW of data centre load to backup supply.	Grid voltage dropped below the level where UPS transfers to back-up supply.	RoCoF of approximately +0.12 Hz/s and a frequency peak of around 50.22 Hz.
7 Dec 2022	US – ERCOT (Far West Texas / Odessa)	A substation fault in a 138 kV area produced a large aggregate loss of power-electronic loads, including data centres, crypto miners and oil and gas facilities.	Voltage-sensitive power-electronic loads subjected to shallow but widespread voltage depressions, including one delayed fault clearing.	Brief system over-frequency event, with frequency taking about 12.5 minutes to return to the normal range.
10 Jul 2024	US – Dominion / PJM (Northern Virginia)	A 230 kV surge arrester failure caused a permanent line fault and three-shot auto-reclosing at each end, producing six voltage dips in about 82 seconds and transfer of roughly 1500 MW of data centre load to backup.	Number of voltage disturbances in quick succession, including auto-reclosing events resulted in transfer to back-up for a large number of data centres.	Frequency peak of about 60.05 Hz and voltages up to approximately 1.07 p.u. in the affected corridor.
Sep–Oct 2024	US – ERCOT (single campus)	A single large campus experienced an active-power oscillation at about 23 Hz with a peak-to-peak magnitude of 40–50 MW when loading exceeded roughly 300–320 MW.	Older firmware and a poorly damped grid-interface controller that became unstable at higher site loading.	Persistent sub-synchronous oscillations.
26 January 2025	Dublin: Poolbeg 220 kV Reactor Fault	A fault on the 220 kV shunt reactor at Poolbeg caused a transient voltage dip across the Dublin area and a collective reduction of about 321 MW of data centre demand, which then recovered gradually over roughly a minute.	Grid voltage dropped below the level where UPS transfers to back-up supply.	Positive RoCoF spike of the order of to +0.2 Hz/s and a frequency peak a little above 50.2 Hz.
17 Feb 2025	US – Dominion / PJM (Northern Virginia)	A step-wise reduction in demand of about 1.8 GW was recorded, associated with large data centres transferring to backup supply.	Number of voltage disturbances in quick succession resulted in transfer to back-up for a large number of data centres.	No material wide-area impact reported, but a large aggregate change in demand within one region.
Feb & Mar 2025	US – AEP (PJM)	Two normally cleared transmission faults, including high-speed auto-reclosing, produced mixed responses from large data centres: some sites rode through on grid supply, while others tripped or transferred to backup.	Number of voltage disturbances in quick succession, including auto-reclosing events resulted in transfer to back-up for a large number of data centres.	Local active-power steps at individual sites of around 70–80 MW.

▲ **Table 5:** List of known international system incidents involving data centres

3.4.2. Learnings for Australia

Looking at incidents in other jurisdictions is useful in identifying the range of scenarios that may happen locally, so we have an opportunity to plan for them.

Based on the incidents in **Table 5**, several common technical themes emerge:

- **Lower voltage ride through capability than IBR plant**

  In most incidents, the data centre was connected under demand-side standards that are materially less stringent (or in some cases absent altogether) than those applied to IBRs or synchronous generation. As a result, short-duration transmission faults that modern IBR plants would normally ride through can instead cause transfers from normal grid supply to backup supply.

- **Auto reclosing sequences causing multiple dips to which the site is susceptible**

  High-speed single-phase or three-phase auto-reclosing produces a sequence of voltage dips within a relatively short period (one to two minutes). While each dip individually may be within the equipment's capability, several dips in quick succession may trigger a response.

  Many sites affected by these international incidents used disturbance counters, or similar logic, within their UPS systems. When the number of voltage dips within a given timeframe exceeds a programmed limit, the controls transfer to the backup supply. This logic is typically intended as a last-resort safeguard, on the assumption that repeated dips indicate an unstable or permanently faulted upstream supply.

  The UPS prioritises continuity and quality of supply to the local IT load and protection of its own equipment over continued support for the wider power system. A clear theme from the incidents is that the expected number and timing of auto-reclosing shots must be explicitly considered when setting these disturbance counters and ride-through rules.

- **Impact of geographic concentration of data centres**

  Geographic concentration of large campuses on a small number of transmission corridors amplifies the system level impact of each of the mechanisms above. A fault on a shared corridor can trigger coherent transfers or oscillatory behaviour that appears as a multi-hundred-MW event, even when each facility is modest on its own.

- **Coherent transfers across large campuses**

  Because data centre rooms within a campus share similar control philosophies and disturbance thresholds, transfers to backup or staged shutdowns tend to occur coherently rather than independently. Once the disturbance counter limit is exceeded, many data centre rooms disconnect from the grid at the same time.

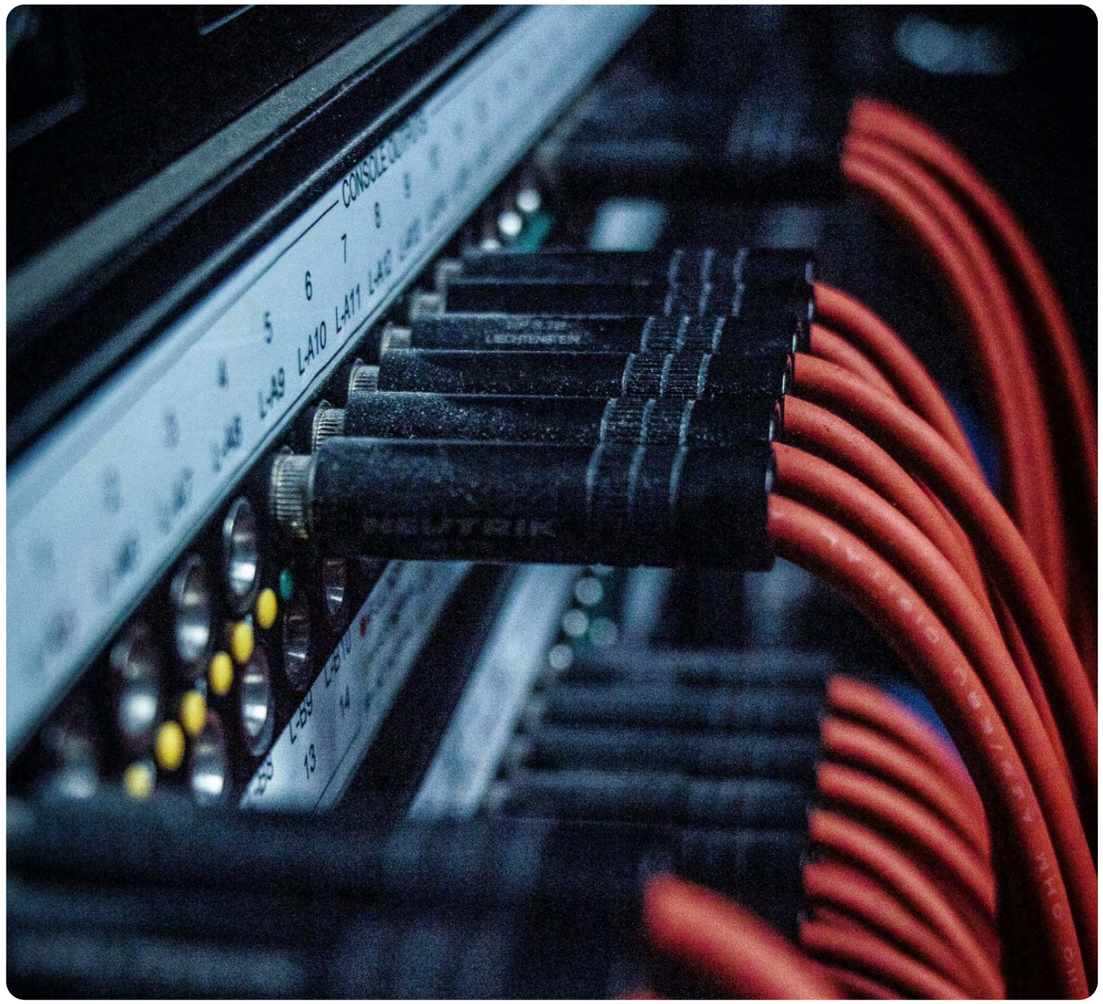
  This can turn what is electrically a single transmission fault into a multi-hundred-MW event at the system level. International experience also suggests that non-IT plants, such as cooling systems and other auxiliaries, can play a significant role in this coherent response, although the specific mechanisms vary from site to site.

- **Forced oscillations and control driven interactions**

  In several cases, the dominant issue has been control-induced oscillations rather than simple step changes in demand or protection-driven trips. Above certain site-specific MW thresholds, marginal tuning or defects in current controllers and phase-locked loops of active front ends, variable frequency drives or UPS rectifiers have excited low-frequency modes in the wider network. These oscillations can be sustained or poorly damped, particularly in areas with lower short-circuit ratio or unusual local impedance characteristics. Mitigation measures have typically involved firmware updates, controller retuning and where necessary, temporary MW caps while fixes are validated.

- **Reconnection and recovery as a second contingency**

  The initial transfer to backup or partial disconnection is only the first stage of the disturbance. Uncontrolled or overly rapid reconnection of large blocks of load during recovery can cause significant swings in frequency and voltage, effectively creating a second contingency. Practical experience has shown that staged reconnection and defined ramp rates are necessary if the process of returning to normal operation does not itself threaten system security.



Challenges at the interface between data centres and the grid, particularly involving UPS systems and associated controls, are at the centre. In the Irish, Dominion/PJM 2024 and later PJM events, UPS transfer logic in response to voltage disturbances is the main driver of large demand steps. In the June 2022 Dominion and Sep–Oct 2024 ERCOT campus events, the dominant issue was an unstable grid-interface controller producing sustained sub-synchronous oscillations, rather than simple UPS transfer or cyclic IT load behaviour.

None of these incidents can be clearly attributed to the behaviour of the IT loads themselves. While IT load behaviours can contribute to system security risks, it hasn't been identified as a major contributor to the events in **Table 5**.

The patterns evident across these incidents map directly to the electrical risk factors discussed in Chapter 5. In particular, they highlight the consequences of limited fit-for-purpose technical standards, incomplete representation of dynamic behaviours, gaps in fault ride-through expectations for large loads, rapid ramping and reconnection, cumulative impacts in geographically concentrated corridors and the potential for frequency instability and forced oscillations.

Chapter 5 draws on these lessons to prioritise which areas require immediate attention in the NEM and Victorian power system context.

4 Data centres and power system performance requirements

Key messages

- The set of disturbances relevant to data centres is broader than classic faults. It includes multiple voltage disturbances in quick succession (including repeated faults due to auto-reclosure), oscillations and resonances (including forced oscillations from pulsing loads), low system strength conditions and power-quality issues including harmonics and flicker.
- Historically, generation in Victoria was located away from demand centres and closer to fuel sources in the Latrobe Valley. Recently, the shift to renewables has seen new generation distributed across north-eastern and western Victoria, reflecting both the technological and geographic nature of the transition reshaping power flows across the network.
- Sudden changes in interconnector flows or network configuration can cause significant frequency and voltage disturbances on the Victorian transmission network. Sensitive loads, such as data centres, may disconnect in response and rapid or simultaneous disconnections can amplify network impacts and increase the risk of unsuccessful contingency recovery. The location, clustering and operational characteristics of new major loads are therefore critical to maintaining Victorian power system security and transmission reliability.
- Large data centres change system operating conditions, particularly by increasing demand during low demand periods that are critical for outage planning. In some cases, this may increase the cost, complexity and risk of planning transmission outages making outage coordination more challenging.
- A scan of international requirements suggests large loads are increasingly expected to behave predictably through grid events, with a focus on voltage and frequency ride-through (staying connected and stable through credible disturbances rather than transferring off-grid), rate of change of frequency (RoCoF) ride-through and defined active-power recovery following fault clearance so recovery does not create a second contingency.
- Several jurisdictions are proposing or formalising these requirements for large demand facilities, in some cases alongside permissions or controls on return-to-service and specified recovery targets.

Chapter 4 covers potential refinements to the performance requirements for data centres:

- The disturbances data centres connecting to the NEM need to plan for (Section 4.1)
- Factoring Victoria's transmission network into data centre site selection (Section 4.2)
- Learning from international jurisdictions' performance requirements (Section 4.3).

4.1. Disturbance conditions in Victoria and the NEM

The Australian power system is inherently complex and sparsely interconnected, with less inherent resilience than more highly meshed grids. It is continually exposed to a wide spectrum of disturbances, both anticipated and unexpected with implications for reliability, security and supply quality.

To manage these challenges, Chapter 5 of the NER establishes technical standards that generators and large loads must account for when connecting. These standards are essential for maintaining system integrity, yet not all circumstances could be forecast when they were written so they must evolve with the rapid emergence of new technologies and changing market dynamics.

The framework was designed for traditional large loads. Currently, data centres are subject to the same rules raising questions about their suitability for this class of load. Striking the right balance is critical. Standards must be robust enough to safeguard the grid, yet flexible enough to avoid creating barriers to innovation and investment.

Table 6 summarises the types of disturbances and operating conditions a data centre connecting in the NEM may be exposed to. Detailed explanations of each are provided in Appendix C.3. The following items may not all be officially defined as disturbances but are relevant for consideration by data centre owners and operators.

Category	Description	
Fault	• Short circuit between one or more phase conductors and/or ground, cleared within a standardised time. • Subsequent faults due to auto-reclose mechanisms in quick succession. • Lightning strikes and flashovers due to bushfires.	• Loss of conductor (without fault). • Extended fault clearance times in the distribution system. • Repeated faults in quick succession during storm events (across multiple circuits).
Voltage	• Sustained voltage reduction due to control or protection error. • Sustained voltage reduction due to excessive customer power draw. • Overvoltages due to failure of reactive compensation plant.	• Overvoltages due to failure of reactive compensation plant. • Failure of voltage regulating transformers. • Spontaneous voltage oscillations due to plant controller misoperation or pulsating customer power draw.
Frequency	• Underfrequency events due to sudden excess of load to generation ratio. • Overfrequency events due to sudden excess of generation to load ratio. • High rate of change of frequency (RoCoF) associated with either event above.	
Oscillations and resonances	• Torsional oscillations between large synchronous machines and the grid (both local and inter-area modes). • Controller interactions of multiple inverter-based resources in a wide area. • Sub-synchronous oscillations (i.e., lower than 50 Hz) between synchronous machines and series network capacitors, or certain wind turbine types and series network capacitors. • Forced oscillations due to a large generator or load misoperating or drawing a regular, pulsing amount of power from the system (e.g., drag-lines and data centres).	
Low system strength	• Insufficient voltage stiffness due to an excess of grid-following generation online, insufficient synchronous machines, or increased network impedance between node and system strength sources.	
Power quality disruption	• Voltage fluctuations due to improper load draw. • Voltage imbalances between phases. • Voltage and current harmonic distortion.	• Flicker (changes in voltage that are noticeable to the human eye through light sources). • Electromagnetic interference.
Low probability disturbances	• System black events.	• Geomagnetic disturbances.

▲ **Table 6:** Disturbance conditions to be considered

4.2. Technical planning considerations specific to the Victorian transmission network

Understanding the structural characteristics of the Victorian transmission network is critical to assessing system resilience and exposure to operational and climate-related risks. These factors should be explicitly considered when determining the location and connection voltage for a new data centre or other large load.

4.2.1. Characteristics of the Victorian transmission network

Electricity demand is concentrated in metropolitan Melbourne and adjoining industrial corridors, while Victoria's historical generation has been dominated by large brown-coal–fired power stations in the Latrobe Valley, far from major load centres.

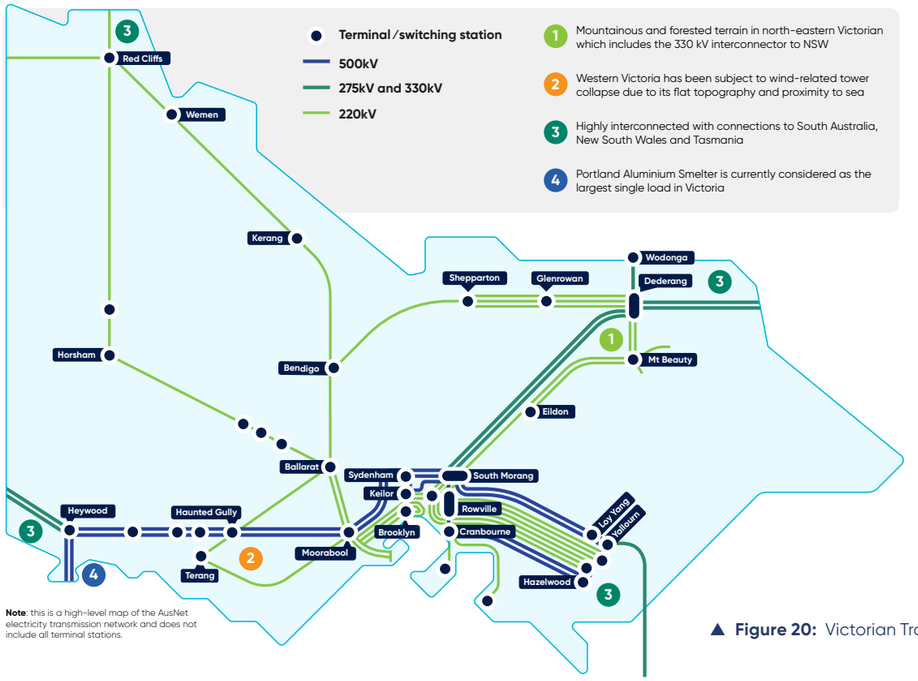
This geographic separation led to the development of a distinctive 500kV east–west transmission backbone to support long-distance bulk power transfer with minimal losses. Within metropolitan areas, closed 220 kV loop arrangements were established to provide redundancy, operational flexibility and resilience to equipment outages.

Victoria's role as a nexus state between South Australia, New South Wales and Tasmania results in a higher level of interconnection than in most other jurisdictions. While this interconnectivity delivers material benefits, including improved supply reliability, it also increases the potential for major disturbances in other regions, or on interconnectors, to propagate into the Victorian transmission system and affect connected plant.

Victoria also faces an elevated risk of frequency instability. The largest allowable contingency in the state is smaller than in other jurisdictions and there is no resecuring reserve to manage large megawatt swings, nor are system integrity protection schemes (SIPS) in place.[61]

Changing climate conditions further amplify these existing structural exposures and introduce additional operational risk that must be proactively recognised and managed. The nature and likelihood of transmission outages are increasingly influenced by local terrain and weather-related hazards, with risk profiles varying significantly across regions.

- **North eastern Victoria** is characterised by mountainous, heavily forested terrain. Victoria's main 330kV interconnector to New South Wales covers extensive bushland that is prone to bushfires. During bushfires, smoke can increase the risk of transmission line flashover. Under high demand and heavy imports, the simultaneous loss of both circuits on this interconnector could lead to widespread load shedding.
- **Western Victoria**, including the 500kV transmission backbone and the 275kV interconnection to South Australia, has experienced rare wind related transmission tower failures caused by convective downbursts. The likelihood of such events may increase as climate risks intensify. Damage to this corridor would expose the Victorian power system to load shedding and prolonged periods of abnormal operation during restoration, with disturbances primarily affecting voltage and frequency and to a lesser extent, power oscillations and resonances.



Note: this is a high-level map of the AusNet electricity transmission network and does not include all terminal stations.

▲ **Figure 20:** Victorian Transmission Network

4.2.2. Inverter based loads on the transmission network

Although Victoria operates one of Australia's most highly meshed transmission networks, sudden losses of import or export capability following an interconnector outage can still cause significant frequency disturbances due to the abrupt imbalance between generation and load. Associated changes in power flows and network configuration can also give rise to voltage disturbances that spread across the interconnected network. Sensitive loads, such as data centres, may detect these disturbances at their connection points and disconnect in response.

In areas with a high concentration of data centres, simultaneous disconnections can materially increase the reliability impact, intensify the original disturbance, complicate frequency arrest and voltage recovery and increase the risk of unsuccessful contingency recovery.

The Portland Aluminium Smelter, with a capacity of 580MW, is currently Victoria's largest single load and is subject to special protection schemes that can rapidly curtail consumption to maintain power system security. Given the well established impact of large discrete loads on system performance in both Victoria and South Australia, it is likely that future large scale loads may also require participation in special protection schemes, depending on their location, connection point and load characteristics.

The clustering of large loads, particularly data centres, compounds the impacts of the geographic shift in generation by altering power flow patterns, increasing sensitivity to local disturbances and heightening reliance on key transmission corridors and terminal stations.

Beyond geographic considerations, changing demand profiles are resulting in more extreme system conditions. On 27 January 2026, Victoria recorded a new maximum system demand of 10,752 MW during temperatures exceeding 40 °C, with the peak coinciding with declining rooftop PV output. This record occurred prior to the connection of identified hyperscale data centres in the future development pipeline (see Section 1.2.4).

Data centres are also expected to materially influence minimum demand conditions, which are a critical input to transmission outage planning. The safe operation and maintenance of the network relies on carefully coordinated outages to minimise market and reliability impacts. The addition of large, inflexible loads is likely to further constrain outage windows without additional network augmentation, increasing the cost, complexity and risk of planned outages. In this context, non outage techniques such as live line work may become increasingly important. The impacts of data centre connections on both maximum and minimum demand should be carefully assessed during connection planning to preserve the long term reliability of Victoria's transmission network.

These factors underscore the importance of proactive transmission planning, coordinated connection timing and explicit consideration of load clustering when evaluating future development pathways.

61. See Section 5.3.5 for more information.

4.3. International requirements

This section considers requirements developed by international jurisdictions, which may aid in understanding the known and expected performance from large data centre loads.

Table 7 provides a comparative summary of the existing or proposed technical performance requirements for loads and DERs across the surveyed regions. These jurisdictions were selected based on the amount of existing large load, maturity of the processes and connection requirements and standards available for data centre performance. For consistency, the same jurisdictions (ACER, ERCOT, NERC/WECC and Fingrid) were selected.

These additional requirements can be found in both ERCOT and NERC proposals:

- Constant current behaviour during the fault.
- Specific consideration of forced oscillations due to load variability. Recognition that some of these oscillations may be in the frequency range between 2 and 4 Hz which is not covered in German requirements for electrolysers.
- Specific consideration of sub-synchronous torsional interactions (see more details in Chapter 5).

Performance aspects	ACER[62] (Europe)	ERCOT[63,64] (Texas)	NERC[65] /WECC[66] (North America)	Fingrid[67] (Finland)	EirGrid[68] (Ireland)
Steady-state reactive power	✓	✓	✓	-	-
Steady-state voltage range	✓	✓	-	✓	-
Steady-state frequency range	✓	✓	-	✓	-
Power quality	✓	✓	✓	✓	✓
Fault ride-through	Proposed	Proposed	Being developed	Required	Proposed
Constant current behaviour during faults	-	Proposed	Being developed	-	-
Recovery following fault clearance	Proposed	-	-	Required	Proposed (≥ 95% pre-fault demand)
Rate of change or frequency (RoCoF) ride-through	Proposed	-	-	Required	-
Permission required to return to service following disconnection	Proposed	-	-	-	-
Minimum SCR	-	-	-	Required (operation at minimum SCR)	-
Ramp rates	-	Proposed	Being developed	✓ (via active power recovery time)	-
Dispatchability	-	Proposed	Being developed	-	-
Curtailment	-	Proposed	-	-	-
Small-signal forced oscillations	-	Proposed	Being developed	-	-
Emergency power control (including load shedding)	Proposed to include ramp-down and load shedding	Ramp-down	Being developed	-	-
Frequency droop	Proposed	-	-	-	-
Interactions and resonances	-	Proposed	Being developed	-	-
Instability monitoring and protection	-	-	Being developed	-	-
Connection study process	Proposed	Required	Being developed	Required (PSCAD / PSS®E models and studies)	Required (connection studies and models)
Ongoing obligations following commissioning	Proposed	Proposed	Likely but not determined at this stage	-	-
MW threshold above which the requirements apply	All MW levels will be subject to these requirements for the three categories of loads specified	75 MW	No single value; typical RTO / ISO screening thresholds about 20–75 MW.	≥ 30 MW demand, ≥ 10 MW data centres (UPS requirement)	Large demand facilities (MW threshold not yet specified publicly)

▲ **Table 7:** Comparison of different jurisdictions with existing/proposed performance requirements for loads of different type and size

62. ACER Recommendation No 01/2025 – Network Code on Demand Response (NC DR)
63. ERCOT Planning Guide (2025)
64. ERCOT, large Electronic Load (LEL) Interim Ride-Through Assessment (Sep 19, 2025)
65. NERC, Draft Reliability Guideline: Risk Mitigation for Emerging Large Loads
66. WECC, An Assessment of Large Load Interconnection Risks in the Western Interconnection, February 2025
67. Fingrid, Draft of updated Grid Code Specifications for Demand Connections (KJV2026), June 2025
68. Eirgrid, Large Demand Facility Fault Ride Through Issue and Proposed Solutions, November 2025

5 Prioritising improvements at the data centre and grid interface

Key messages

- Risks are prioritised by relevance and timeline and grouped into:
  i) process and information gaps
  ii) power system impacts, to focus effort where it reduces system security risk fastest.
- The immediate priorities are to close process and information gaps, particularly stakeholder coordination and fit-for-purpose technical requirements and standards, before project-by-project approaches drift into inconsistency.
- Limited representation of dynamic behaviours is a near-term priority, because missing or oversimplified UPS logic, staged reconnection and credible variability envelopes can materially change assessed disturbance and recovery outcomes.
- Fault behaviour and recovery (ride-through, transfer-to-backup and reconnection profile) is the most pressing technical issue, because coherent MW offloading and recovery during fault and reclosing sequences can translate a local disturbance into a power system security event.
- Rapid MW variability (ramp rates and seconds-scale cycling) is a near-term technical priority, because normal-operation variability can increase the duty on frequency control and reserves and if correlated across sites, materially increase aggregate ramps.
- Secondary but important technical risks include clustering and coherent corridor response (including susceptibility to correlated behaviour in areas with high DPV and other inverter penetration) and power quality and resonance, which are more location-dependent but can be severe where corridor impedance and configuration create sensitivity.
- Data centres should not be treated as generators by default and IBR-oriented mechanisms and access standards should not be applied without adaptation. Requirements should reflect load roles, incentives and site control behaviour.

This chapter:

- Identifies the data centre and grid interface areas that most need addressing (Section 5.1)
- The process and information gaps that need to be filled (Section 5.2)
- Power system impacts (Section 5.3).

5.1. Identifying areas that need improvement

5.1.1. Overview

Using recent Australian and international experiences and factoring in the system security needs of the NEM and Victorian power system, this section presents the priority risk factors for integrating data centres into the power system.

Identified risks are divided into two categories discussed further in sections 5.2 and 5.3.

- **Process and information gaps:** The risks focus on the existing gap in the process or lack of process. The intent of this criterion is to provide clear visibility to stakeholders and regulatory bodies.
- **Power system impact:** The risks focus on the power system performance implications and overall system stability and supply quality. Each of these impacts can be linked to various aspects of power system stability phenomena (e.g. frequency stability, voltage stability etc). However, these phenomena would be highly interlinked and therefore further sub-classifications have been avoided.

5.1.2. Risk factor assessment approach

Risk prioritisation is guided by both relevance and timeline. Each risk ranking is informed by both recent experiences and expert insights, so that planning and implementation efforts tackle the most critical problems first while still allowing new connections to proceed. Risks that have a high impact in the form of relevance should be addressed first as they pose immediate concerns to power system performance.

The risks in this section have been scored for relevance and timing using the following definitions. Further detail on our approach is available at Appendix D.

Relevance score definitions

- **Critical:** A connection gating issue for secure operation, if not addressed it is likely to create an unacceptable system security risk under credible disturbance sequences. Requires mandatory requirements and fixes before energisation.
- **High:** Credible and potentially material under foreseeable scenarios, but can be managed if explicit requirements, modelling scope and operational controls are defined and implemented in the near term. Not inherently a blocker provided the controls are effective.
- **Medium:** Credible but more conditional or location-dependent, typically managed through targeted studies, design choices and monitoring rather than universal requirements.
- **Low:** Not expected to be a primary driver under foreseeable scenarios or likely managed through existing practices.

Timeline definitions

- **Immediate:** Needs to be addressed now to support current connection activity and near-term operational security.
- **Short-term:** Expected to become material within approximately 1–2 years, or requires groundwork now (standards, modelling scope) to avoid becoming a project blocker.
- **Medium-term:** Expected to become material within approximately 3–5 years, typically driven by clustering, corridor build-out or evolving operating behaviour.
- **Long-term:** More likely beyond 5 years or strongly contingent on technology evolution and uptake.

5.1.3. Assessment of each risk factor

Table 8 provides the overall relevance and timeline scoring at NEM scale. The corresponding relevance for Victoria and any differences from the NEM score, are stated and justified in the subsequent subsections for each risk factor.

Risk Factor	Relevance	Timeline
Process and information gaps (Section 5.2)		
Coordination between stakeholders	Critical (NEM & VIC)	Immediate
Defining fit-for-purpose technical requirements and standards	Critical (NEM) Medium (VIC)	Immediate
Limited representation of dynamic behaviours	Critical (NEM & VIC)	Short-term
Rapid connection timelines	High (NEM) Medium (VIC)	Short-term
Observability	High (NEM & VIC)	Medium-term
Insufficient compliance enforcement	High (NEM & VIC)	Medium-term
Lack of forecasting and predictability	Medium (NEM & VIC)	Medium-term
Capacity creep	High (NEM) Medium (VIC)	Medium-term
Most pressing power system impacts (Section 5.3)		
Rapid ramp rates	High (NEM & VIC)	Short-term
Additional concerns on lack of fault ride-through	Critical (NEM & VIC)	Short-term
Excessive price responsiveness	Medium (NEM) Low (VIC)	Medium-term
Power quality impact including harmonic resonances	Medium (NEM & VIC)	Medium-term
The risk of frequency instability	Medium (NEM) High (VIC)	Short-term
Forced oscillations	Medium (NEM & VIC)	Medium-term
The risk of exciting torsional modes of oscillations	TBD[69]	TBD

▲ **Table 8:** Risk factor summary

Table 9 translates each power system risk factor into the system-level consequences that matter for system security and grid connections, so the implications of each risk are clear and can be traced through to study scope, requirements and monitoring needs.

69. TBD denotes that a relevance ranking and timeline have not been assigned because NEM/VIC-specific materiality and credible triggering conditions are not yet sufficiently established; these will be refined through targeted investigation using fit-for-purpose dynamic representations which is not universally available to date.

Power System Impacts	Consequences
Rapid ramp rates	Poor frequency control, localised voltage control issues
Additional concerns on lack of FRT	Frequency and voltage control challenges during faults and recovery, potential activation of emergency control schemes, and in adverse cases cascading failures and widespread disruption.
Excessive price responsiveness	Frequency control burden, localised voltage issues, and adverse market outcomes (price volatility and inefficient dispatch).
Power quality impact including harmonic resonances	Excessive voltage distortion and flicker, equipment stress and potential damage, and nuisance tripping, which in resonant conditions can escalate into wider system security impacts.
The risk of frequency instability	Short-term frequency deviations and increased duty on frequency regulation and contingency reserves.
Forced oscillations	Sustained power and voltage oscillations that can degrade power quality and increase equipment stress, and in severe cases trigger protection or control actions that escalate into broader system security consequences.
The risk of exciting torsional modes of oscillations	Torsional stress risk for thermal plant, potentially leading to protective action or disconnection, and in severe cases, equipment damage.

▲ **Table 9:** Consequences of risks

5.1.4. Key recommendations on the most pressing power system performance issues

- **Process and requirement gaps (connection studies, technical requirements and modelling requirements):** The most immediate priority is to close the gaps in how large data centres are specified, studied and coordinated across parties. Without a common, fit-for-purpose framework, projects can progress on inconsistent assumptions, creating the potential for rework, uneven requirements across proponents and study outcomes that are not robust.
- **Fault behaviour and recovery (ride-through, transfer-to-backup and reconnection profile):** Transfer to backup during faults and the reconnection and recovery profile after faults, should be treated as part of the same "event" and subject to minimum, consistent standards. The system impact is driven by coincident MW reduction during voltage disturbances (including auto-reclose sequences) and by how quickly and coherently load returns. This is a near-term priority for both the NEM and Victoria and it underpins fit-for-purpose ride-through expectations, including defined recovery ramp rates.
- **Rapid MW variability (ramp rates, seconds-scale cycling and price-driven behaviour):** Fast changes in demand can be material in normal operation, not only during disturbances. This increases the duty on frequency control and reserves at NEM level. In Victoria, the materiality depends on how much capacity connects in the region and whether behaviour is correlated across multiple sites. This highlights the need for clear and realistic assumptions on ramping and variability at the connection point and for studies to reflect credible operating modes rather than idealised "steady" demand.
- **Power quality and resonance (flicker, unbalance and harmonic resonance):** Even if individual sites comply with emissions limits, network interactions can amplify voltage fluctuation and resonance phenomena, particularly where network impedance characteristics, long HV cables, reactive compensation and large transformers create resonant conditions. This is expected to be more location-dependent than the other issues and can be particularly relevant where transmission-connected data centres and corridor characteristics make resonance more likely. These phenomena are not solely "quality of supply" concerns, they can also create system security impacts. Early screening, fit-for-purpose study methods and adequate monitoring are therefore critical so issues are identified before they escalate into operational events.

In summary, not all issues are urgent in all locations. Our view is that a small set of well-understood, high-necessity actions should be prioritised over the next one to two years – particularly where there is clear and urgent need and that provide a foundation for the connection process – these are prerequisites for addressing several secondary risks. These include clarifying fit-for-purpose technical and modelling requirements and making sure studies capture disturbance behaviour end-to-end (including transfer and recovery) and credible envelopes for rapid MW variability. These actions are explored further in Chapter 6.

Other potential impacts are less mature and more location-dependent and should be progressed through targeted investigation and monitoring rather than being treated as immediate, universal requirements. This approach avoids diverting effort toward issues that are more time-consuming, less characterised and not currently the primary risk drivers for large-scale data centre connections.

5.2. Process and information gaps to be rectified

5.2.1. Coordination between stakeholders

Processes to coordinate and standardise connection studies and load modelling approaches are still developing. As explored in Chapter 1, inconsistency and unclear requirements are a major pain point for data centre developers (and can also lead to delayed solutions and higher operational risks for network service providers and AEMO).

Stakeholders often use different technical vocabularies and conventions and their respective challenges and constraints are not always known to one another. For inverter-based resources, mutual understanding between network service providers, AEMO, developers and OEMs is comparatively mature. They're built over several years of projects, standards development and a shared language around modelling and technical performance.

For data centres, this mutual understanding is still growing. Developers and OEMs often have a limited grasp of network planning, operational philosophies, modelling and technical performance needs. Conversely, the electricity sector is still building its understanding of data centre architectures and behaviours such as UPS operating modes, fault ride-through controls and the reasons why certain restrictions are in place.

Differences in modelling and study approach, milestone expectations and information visibility across parties prolong queues and create uneven assumptions, which increases rework and extends timelines.

Risk factor assessment

- **Relevance to the NEM:** Critical
- **Relevance to VIC**: Critical
- **Timeline:** Immediate
- **Reasoning:** The issue is not unwillingness, it is limited mutual visibility of each party's challenges and constraints and inadequately specified modelling and performance requirements. This can lead to inconsistent assumptions between parties, late rework, uneven requirements between projects and connection outcomes that are not robust, which is why the issue is scored critical and immediate.

5.2.2. Defining fit-for-purpose technical requirements and standards

Technical requirements for large load connections under NER Schedule 5.3 are still being defined in the NEM. There is ongoing work led by AEMO and the AEMC to investigate what technical requirements will be necessary in the near term to facilitate the anticipated growth of data centres across the NEM, including a draft rule released in March 2026.[70] Some network service provider-specific guidelines are in force or being developed. For example, VicGrid's data centre connection guidelines released in Feb 2026 only set technical performance requirements for transmission-connected data centres in Victoria.

Technical performance requirements for data centre connections should reflect the behaviour of power-electronic components, including UPS rectifiers, inverters and VFD-driven pumps and compressors and be guided by the real world performance of these components and the integrated system. Credible requirements depend on sufficiently accurate models of these systems, yet high-quality models are often only produced once clear requirements exist, which creates a circular dependency.

Ambiguity about which reference curves and standards to follow leads to inconsistent fault ride-through assumptions and study outcomes across projects. Without detailed information and mature models, stakeholders have sometimes used automatic access standards for IBRs as a reasonable initial proxy. While the intent is understandable, it is noted that data centres are not generators; their operational philosophy, controls and protection logic are materially different. Therefore, adopting generator oriented access standards can result in technical requirements and study approaches that are not suitable for large loads.

Generator-oriented compliance frameworks, study processes and performance obligations shouldn't apply to data centres by default, noting the different roles and incentives of load versus generation. We shouldn't assume generator-specific instability mechanisms always translate directly to data centres without supporting studies. At the same time, data centres may present load-specific susceptibilities. For example, cyclic or pulsing power behaviour and rapid mode transfers, which reinforces the need for fit-for-purpose requirements.

A lack of clearly defined technical requirements throughout the lifecycle of a data centre connection project introduces significant challenges. Frequent or late-stage changes to performance expectations can lead to unanticipated costs, project delays and increased uncertainty for data centre developers. This undermines investment confidence and complicates the design and procurement of equipment, particularly when long lead times and custom engineering solutions are involved. Many the relevant power-electronic subsystems are procured as integrated packages with tightly coupled controls and protection features and changes to performance expectations can require rework across multiple vendors and interfaces.

Where bespoke settings, firmware changes or additional control modes are needed, these are often non-standard, carry extended development and verification cycles and may have limited availability across OEM product lines. As a result, late changes can translate into materially higher delivery risk, including re-modelling, re-documentation and contractual re-negotiation. A consistent and transparent framework is therefore essential to support efficient project delivery and maintain alignment with broader power system planning objectives.

Risk factor assessment

- **Relevance to the NEM:** Critical
- **Relevance to VIC**: Medium
- **Timeline:** Immediate
- **Reasoning:** Requirements and performance co-evolve. If the circular dependency is left unaddressed and data centres are treated like generators, the result is non-evidence-based requirements and models that fail to reflect real data centre behaviour in the NEM. This can lead to inconsistent assumptions and late rework and either under-manage material behaviours or impose overly conservative constraints that increase cost and uncertainty without improving system security.

  In the Victorian context, recent guidelines from VicGrid have resulted in the Victorian power system having a more consistent approach to the connection and assessment of new data centres, however these do not cover all aspects of risk and performance identified in this paper.

70. AEMC, Improving the NEM access standards – Package 2, Draft rule determination, March 2026

5.2.3. Limited representation of dynamic behaviours

There is no widely adopted, fit-for-purpose modelling standard for data centres. Inverter-based resource connection studies often rely on user-written or vendor-specific models but these models are not yet commonly available for data centres. Traditional static load models – for example, ZIP (constant impedance, current and power) or CMLD (composite load model) - are inadequate for disturbance and recovery analysis. This is because they miss key behaviours of power-electronic front ends and site controls that govern how data centres respond during and after grid disturbances.

Critical dynamics are frequently missing or oversimplified, including:

- active-rectifier and inverter fault ride-through characteristics (constant-power behaviour, current limits, phase locked loop (PLL) and firmware effects)
- cooling plant behaviour (VFD trips, re-starts, and delayed recovery)
- staged reconnection and ramp-rate limits at the connection point
- UPS transfer logic and disturbance counters ("count-to-N") that can trigger mass, coincident transfers to back up after ordinary faults.

We understand there are many cases where UPS protection and control settings, fault ride-through curves, tolerance to successive faults and other important modelling details are also incomplete or unavailable for network service providers to review as part of the connections process.

Similarly, an oversimplified representation of the IT workload can mask fast demand variability and correlated behaviour across racks or sites, which affects assessed ramp rates and post fault active power recovery trajectories at the connection point. In practical terms, this can cause studies to miss cyclic or pulsing power behaviour and its potential interaction with site controls and the network during recovery.

The implication is that disturbance and recovery studies may materially mischaracterise operational risk, including the likelihood and timing of large, coincident load reduction and delayed or staged recovery. This can lead to study outcomes that either understate system security concerns, or overstate them and drive unnecessary requirements, both of which increase cost and uncertainty. In the near term, these gaps can become a practical connection and commissioning risk, because the absence of agreed dynamic scope and evidence expectations can delay approval, drive late design changes or force overly conservative assumptions to maintain system security.

It is worth repeating that despite the noted challenges from developers and OEMs in the uncertainty of developing compliant power system models of their data centre equipment, our experience indicates that detailed dynamic models can be developed for key technologies. This suggests that the main barrier is not necessarily technical capability or lack of willingness, but the lack of a unified framework that clearly defines modelling requirements.

Dynamic representations will often focus on UPS, rectifiers, inverters and site-level controls, while the IT workload is represented using simplified demand profiles rather than detailed deterministic models, particularly for AI workloads. Where simplified profiles are used, they should still bound credible ramping, pulsing and recovery behaviours and explicitly represent any operating modes that change disturbance response - for example, different redundancy or backup configurations.

Power quality and harmonics are important but are typically assessed via separate harmonic and measurement-based studies, rather than the dynamic models discussed here.

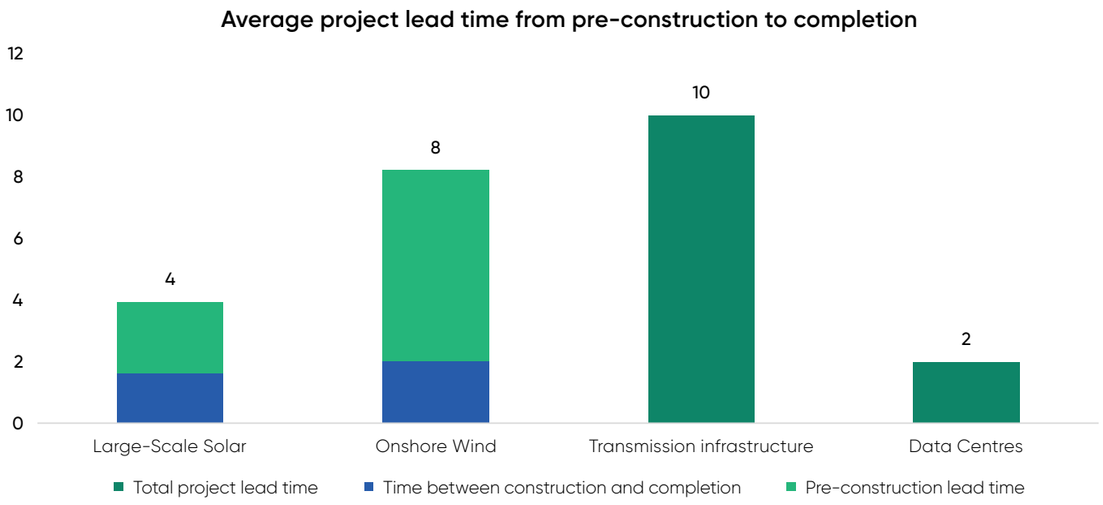
Risk factor assessment

- **Relevance to the NEM:** Critical
- **Relevance to VIC**: Critical
- **Timeline:** Short-term
- **Reasoning:** Model gaps around UPS transfer logic, successive-fault tolerance and staged reconnection are already affecting study fidelity and system security risk as large AI campuses proceed. The issue is not that dynamic models cannot be developed, it is that submissions frequently lack a fit-for-purpose dynamic representation of the behaviours that most influence assessed dynamic performance at the connection point. If left unaddressed, studies can materially understate or overstate risk, leading to rework, inconsistent requirements between projects or controls that are not appropriately targeted.

  The timeline is short-term rather than immediate because model uplift is most effective once there is upstream alignment on fit-for-purpose requirements, agreed study scope and evidence expectations across stakeholders. This does not imply that high-quality dynamic models cannot be developed now, but consistent and comparable outcomes are most reliably achieved when the enabling requirements and coordination mechanisms are established.

5.2.4. Rapid connection timelines

Data centre proponents typically seek connection on highly compressed schedules, with projects often progressing from pre-construction to completion within two to three years. By contrast, transmission-connected solar and wind projects typically require between four to eight years as shown in **Figure 21**.



▲ **Figure 21:** Average project development lead-times in Australia

71. See following for large-scale solar and onshore wind lead-times: Clapin, L., & Longden, T. (2024). Waiting to generate: An analysis of onshore wind and solar PV project development lead-times in Australia. Energy Economics, 131, 107337. https://doi.org/10.1016/j.eneco.2024.107337.
72. Transmission and data centre lead-times based on internal view.

This disparity reflects the distinctive nature of data centre services demand, which can emerge and scale rapidly. Accordingly, data centre proponents plan across comparatively short timeframes – with a short-term horizon of around three months and a long-term horizon of 10 years.

These compressed timelines are further intensified by rapid technological change and growing expectations that digital services perform almost instantly. Hardware configurations, particularly GPU technologies, evolve quickly and may require frequent upgrades, while end user requirements can shift abruptly and with limited notice. As a result, data centre projects are designed with a strong emphasis on flexibility and ability to expand, reconfigure or repurpose facilities to support rapid initial delivery and ongoing adaptation to fast-moving technology and consumer behaviours.

However, data centre development timelines sit in tension with the longer planning and delivery cycles of the transmission network. Network augmentation and major transmission projects typically span a decade, increasing the risk that network constraints or mitigation requirements are identified late in the data centre development process. When this occurs, there is limited opportunity to redesign facilities, stage load commencement, or implement network and operational solutions prior to energisation.

These compressed development timeframes pose material challenges for network service providers and AEMO. Limited lead times restrict the ability to undertake detailed studies, fully assess impacts on the broader power system, and deliver necessary infrastructure upgrades or mitigation measures. This increases the risk that system security and stability issues are not fully identified or addressed prior to connection, creating operational challenges once large, inflexible loads are energised.

Risk factor assessment

- **Relevance to the NEM:** High
- **Relevance to VIC**: Medium
- **Timeline:** Short-term
- **Reasoning:** Relevance is scored higher for the NEM because the pressure is driven by aggregate volume and concurrency across jurisdictions. Multiple states are progressing large data centre connection pipelines in parallel, and near-term activity in NSW, and increasingly Victoria, means the impacts accumulate at a system level through constrained planning and study capacity, potentially inconsistent requirements, and limited time for mitigations to be standardised and implemented.

  The Victorian score is lower because it reflects local exposure and near-term plausibility within Victoria rather than the full NEM-wide pipeline and should be revisited if the proposed connection pipeline accelerates. The timeline is scored Short-term because these compressed schedules are already shaping study scope, coordination burden, and mitigation delivery for the next wave of connections, and will become a practical driver of requirements and project outcomes within the next 1–2 years.

5.2.5. Observability

Accurate assessment of data centre behaviour and post-fault performance depends on what is visible at the connection point. At many points of connection, high-resolution measurements are not available, limiting validation of seconds-scale cycling and fault ride-through behaviour against real disturbances. This is due to the absence of high resolution (PMU or DFRs) devices at the site. Per-phase, high-rate connection point measurements (PMU or DFR class) are needed to characterise seconds-scale cycling and fault ride-through response. Validation quality hinges on data quality and resolution. Some non-linear behaviours will not be captured in aggregate models even after tuning and credibility improves only when responses to multiple, varied real disturbances across different operating conditions are compared with simulation.

Risk factor assessment

- **Relevance to the NEM:** High
- **Relevance to VIC**: High
- **Timeline:** Medium-term
- **Reasoning:** The relevance is high because observability underpins model validation, setting verification and early detection of problematic behaviours. The timeline is medium-term because the greatest benefit is realised as monitoring coverage and integration mature, but targeted deployment at new connections can deliver near-term value where elevated risks are identified.

5.2.6. Insufficient compliance enforcement

With technical performance requirements for large data centres still being defined[73] and without sufficiently detailed models to test against, meaningful compliance enforcement is not practical.

Transmission-connected IBRs typically have explicit, testable obligations and routine compliance monitoring requirements as prescribed in the NER, while data centres as inverter-based loads generally do not yet have such obligations.[74] This asymmetry creates a compliance gap: performance cannot be specified, demonstrated or verified consistently, so enforcement is limited regardless of intent. This gap widens and increases power system operation risk as size increases to levels where poor or unknown/unexpected data centre performance can have material destabilising effects on the broader power system.

This compliance gap may also create inconsistency between NSP evaluations of data centre impacts on the power system, especially at a distribution level where autonomy is higher. Depending on the company philosophy and network risk profiles, some network service providers may conduct overly burdensome assessments of plant performance, while others may encourage data centres to connect as quickly as possible without appropriate scrutiny while there are no binding standards in place.

Risk factor assessment

- **Relevance to the NEM:** High
- **Relevance to VIC**: High
- **Timeline:** Medium-term

  Reasoning: Without data centre-specific requirements and sufficiently detailed models, performance cannot be specified, demonstrated or verified consistently. In the meantime, data centres may experience wildly different requirements between network service providers and projects.

  The relevance is high because weak compliance pathways increase the risk that as-built settings and firmware behaviour diverge from study assumptions, undermining system security controls over the asset life. The timeline is medium-term because the risk grows with the number of connections and the need for ongoing assurance, but groundwork is required now to establish practical verification and change-control expectations.

73. It is noted that the recently published guidelines from VicGrid go some way to address this issue but do not cover all risk elements identified in this paper.
74. The AEMC is currently considering options to encourage non-registered Schedule 5 Plant (which includes some data centres) to comply with their applicable performance standards. This recognises that under NER Clause 4.15, the AER can cannot take enforcement action against non-registered participants.

5.2.7. Lack of forecasting and predictability

Data centre demand is difficult to forecast:

1) The development pipeline is often confidential - locations, timing and sizes may not be disclosed until later, giving limited early warning of where and when large blocks of demand will land.

2) Even when projects are announced, planning data can be incomplete or inconsistent (e.g. mixing connected load, peak demand and load factor). Operators need time-series load profiles.

3) Operating behaviour can change quickly - ramps of hundreds of megawatts per minute, seconds-to-minutes variability and regular seconds-scale cycling, can widen short-term uncertainty and increase reserve needs. During faults, mass transfers to backup (and later reconnection) can also cause realised demand to deviate sharply from forecasts.

These challenges are further complicated when predictions are required during the grid connection application process, but the connecting party is a build-to-sell or turnkey developer (intending to sell the asset on to another party after completion). Such developers have no reasonable way of determining the future owner's load profile at an early stage.

Moreover, sustained forecast uncertainty can increase dispatch and reserve uncertainty in operations and reduce planning confidence for corridor augmentation and constraint management. System operators rely on load forecasts to schedule generation and reserves, so improved visibility of time-series load profiles and likely operating envelopes can reduce discrepancies between scheduled generation and realised demand during real-time operation.

Risk factor assessment

- **Relevance to the NEM:** Medium
- **Relevance to VIC**: Medium
- **Timeline:** Medium-term
- **Reasoning:** Sustained uncertainty in the location, timing and operating envelopes of large data centre connections can materially affect corridor planning and operational preparedness and increase the likelihood that other risks, such as clustering and capacity creep, emerge without timely mitigations. This is scored medium because it is generally an enabling risk rather than a standalone technical mechanism. The timeline is medium-term because the materiality scales with connection volume and clustering and becomes a stronger driver as multiple large projects progress in parallel.

5.2.8. Capacity creep

Data centres may initially be built and connected at a relatively modest scale, with connections appropriately made at lower voltage parts of the grid. Over time, these data centres may seek and receive multiple expansion approvals, including additional connections to the grid. As a result, what begins as a small facility can grow into a load of several hundred MWs in a piecemeal fashion.

Such scenarios may avoid adequate levels of performance scrutiny or result in connections to inappropriately sized network infrastructure.[75] It may also lead to scenarios where TNSPs are unaware of long-term site development plans (only initial connection) and therefore cannot optimise network plans considering the wider system needs over time.

Risk factor assessment

- **Relevance to the NEM:** High
- **Relevance to VIC**: Medium
- **Timeline:** Medium-term
- **Reasoning:** This is more likely to occur when there are no clear assessment standards, including standards on the impact of aggregate inverter sources on the network. Relevance is scored higher for the NEM because capacity creep is driven by aggregate uptake across multiple jurisdictions, so system-wide effects accumulate as more sites expand in parallel. The Victorian score is medium because it reflects local exposure and near-term plausibility within Victoria and should be revisited if a large share of the national hyperscale pipeline concentrates within network corridors that cannot support them.

5.3. Most pressing power system impacts

5.3.1. Rapid ramp rates

Data centres can change their electricity usage with computing loads ramping up or down along with intermittent cooling equipment at a rate much faster than anything the power system has dealt with before. This can occur independently to prevailing power system conditions and expose operators to large, sudden demand swings making it harder to maintain system frequency within the limits and requiring more reserves.

This is a high, short-term issue for the entire NEM.

Large, fast ramp-ups or ramp-downs in data centre loads, both from server workloads and from cooling plant starts/stops, are unprecedented from a power-system perspective compared with other loads connected to date (see section 3.2 for representative load profiles). In many jurisdictions, technical requirements do not specify maximum permissible ramp rates or limits on the rate-of-change of power (dp/dt), leaving operators exposed to sharp changes. Large inverter-based loads can ramp demand bidirectionally at rates of hundreds of megawatts in seconds[76], which can materially increase frequency regulation effort and operational reserve requirements if not bounded by fit-for-purpose envelopes and operating constraints.

In addition to discrete ramps, compute workloads show regular seconds-scale power oscillations (≈0.5–5 s) that widen system frequency variability and increase frequency regulation effort, even when average ramps look modest.

Rapid load ramping may also have implications for managing reactive power to maintain stable voltage levels on the relevant network – including the amount of fast-acting support required.

Risk factor assessment

- **Relevance to the NEM:** High
- **Relevance to VIC**: High
- **Timeline:** Short-term
- **Reasoning:**
  - **System-wide versus local:** This is scored high at NEM level because fast MW variability is fundamentally a system-wide operational issue. As penetration increases, the aggregate MW at risk grows and correlated behaviour across multiple sites can materially increase the net ramp, regulation duty and reserve requirements.
  - **Why VIC is also high:** The Victorian relevance is primarily an exposure question - it depends on the scale, concentration and correlation of hyperscale connections and on how those sites operate. However, with multiple prospective connections above 1 GW, it is material where and when these connections proceed, rather than being reduced or elevated by jurisdiction label alone.
- **Why the timeline is short-term:** Ramp and variability assumptions need to be defined early to avoid inconsistent study assumptions and requirements as projects progress through connection and so operational envelopes are credible for near-term planning and preparedness.

75. We understand that Clause 5.3.12 of the NER is the primary mechanism by which load plant alternations are managed.

76. NERC Large Loads Task Force (2025), Characteristics and Risks of Emerging Large Loads, July 2025.

5.3.2. Additional concerns on lack of fault ride-through

The electricity supply and demand must stay in balance to maintain power system stability. The behaviour of the large data centres loads can have the same impact to the power system as large generators because sudden drops or increases in energy consumption can push the frequency and voltage beyond safe operating limits triggering generator or load shedding.

While there are clear requirements concerning fault-ride through (the ability to stay connected during a fault) for generators, which must be satisfied during the connections process, there is currently no similar requirement for large loads like data centres (although work has been progressed).

This is a critical, short-term issue for the entire NEM.

Keeping the grid stable and reliable requires that the amount of online generation always meets the demand. If either of these aspects suddenly changes, the grid can become unstable.

Traditionally the focus has been on keeping generators connected to the system during grid disturbances, but as the size of large loads (such as data centres) increase to levels comparable with some of the largest power stations in the country, there must be additional focus and scrutiny on large load performance to prevent sudden imbalances that can drive frequency and voltage excursions. For example, an abrupt reduction in load can result in over-frequency and voltage rise, prompting generator run-back or in more severe cases, generator trips due to over-frequency generation shedding schemes, whereas a large, coincident reconnection or rapid load ramp can contribute to under-frequency and activate automatic load shedding schemes.

Fault ride-through capability is critical for maintaining grid stability during and after disturbances. When loads unreasonably disconnect each time a temporary supply dip (fault) occurs, it can result in cascading failures and widespread disruptions.

Two data centre behaviours materially affect the power system:

- UPS transfer on disturbances: many sites detect voltage anomalies and transfer critical load to UPS/battery. If conditions persist, on-site generation starts. To the grid, this appears as a sudden MW drop followed by staged reconnection.
- Disturbance-counting logic ("count-to-N"): facilities may remain online through a single dip but transfer if multiple dips occur within a minute (e.g. three dips in 60 seconds), which can align with multi-shot auto-reclosing and cause coherent mass transfers off-grid.

Risk factor assessment

- **Relevance to the NEM:** Critical
- **Relevance to VIC**: Critical
- **Timeline:** Short-term
- **Reasoning:**
  - **Type of load and connecting context:** At hyperscale, data centres are comparable in size to large power stations and IBRs, so their site-level resilience actions can translate into system-level events.
- **Why NEM is critical:** The NEM is critical because coincident transfer-to-backup across one or more sites can create contingency-scale net MW changes that challenge credible contingency planning and can require additional operational safeguards if not constrained.
- **Why VIC is also critical:** The initiating conditions are common across jurisdictions (faults and reclosing sequences). Where large data centres connect in Victoria, the same disturbance exposure can drive system-relevant outcomes, so Victorian relevance should not be assumed lower on geography alone.
- **Why timeline is short-term:** This needs to be addressed now because outcomes are highly sensitive to project-specific thresholds and settings (transfer logic, successive-disturbance tolerance and reconnection profile). If these are not specified and represented explicitly, studies tend to default to generic assumptions that are not robust.

5.3.2.1. Frequent and excessive disconnections

Many data centres may disconnect from the grid during even minor grid fluctuations due to restrictive voltage and frequency protection settings, increasing the risk of wider system instability.

Furthermore, rapid and unpredictable data centre disconnections hinder network service providers' and AEMO's ability to manage contingencies effectively. In practice, ordinary circuit reconnection processes following a fault can produce short voltage dips within a couple of minutes. However, some data centre controls may use disturbance "counters", so successive dips inside that window can trigger a large, mass-coincident data centre disconnection from the grid and transfer to backup.[77] To the system this appears as a sudden contingency, followed by a complex recovery.

5.3.2.2. Uncertain reconnection following the disturbance clearance

Delayed reconnection after a disturbance can adversely impact voltage and active-power recovery, with different thresholds for different parts of the data centre load (e.g. IT equipment versus cooling systems). Further concerns are indefinable reconnection timing. Depending on large load reconnection times, the power system angle may rapidly accelerate (i.e. too much generation compared to load), leading to transient power system instability.

Some sites may reconnect too quickly, others too slowly. Where sites have islanded on UPS/generators, uncoordinated or very fast reconnection can create secondary frequency/voltage swings. Staged reconnection, with defined dwell times between groups and explicit ramp-rate limits at the connection point, reduces this risk and supports stable system balancing.

5.3.2.3. Constant power behaviour during and after the fault

Servers and cooling systems in data centres tend to maintain a constant power consumption regardless of voltage variations. These loads draw higher currents during voltage disturbances to maintain their power consumption. Since power is the product of voltage and current, a drop in voltage forces the load to draw more current to sustain the same power level. This behaviour adversely impacts both the response during the fault and voltage recovery after the fault clearance and is not generally the base load performance assumption with which stability limits have been historically calculated in the NEM.

5.3.2.4. The risk of unmet demand

Without sufficient ride-through capabilities for power system disturbances, the grid may require significant operational constraints for system security and to mitigate the risk of a data centre disconnecting. Under certain conditions, these constraints could substantially reduce the system's capacity to meet electricity demand.

77. An analogy can be drawn here to the events which precipitated the 2016 South Australian system blackout, except rather than fault counters on wind turbines resulting in a mass disconnection, data centres would be disconnecting.

5.3.3. Excessive price responsiveness

Some large loads, such as cryptocurrency mining facilities, change their demand based on price signals. Price-dependent behaviours can vary between individual sites so the combined behaviour of data centres can be particularly unpredictable. This makes it harder for operators to keep supply and demand balanced and maintain frequency stability when it matters most, such as during periods of low reserve and during contingency events.

This is a medium risk for the NEM and low risk for Victoria with a medium-term timeline.

Large price-responsive loads (e.g. cryptocurrency mining facilities) can change consumption rapidly in line with wholesale prices. Because triggers, thresholds and ramp limits vary by site, the aggregate response during scarcity events is uneven and not necessarily coordinated with system stability needs. This behaviour can disrupt ancillary services, particularly frequency control, as these loads rapidly adjust their consumption based on price signals rather than system stability needs. The challenge is further compounded by their very fast ramp-up or ramp-down capabilities, which enable them to make sudden, large changes in power demand. Such volatility introduces additional complexity for system operators in maintaining frequency stability and balancing supply and demand during critical events.

Risk factor assessment

- **Relevance to the NEM:** Medium
- **Relevance to VIC**: Low
- **Timeline:** Medium-term
- **Reasoning:** This risk is conditional rather than inherent - it depends on whether a data centre is operated to follow wholesale price signals. It is scored medium for the NEM because price-driven behaviour is triggered by NEM-wide scarcity and market conditions. At scale uncoordinated responses can create correlated ramps and rebounds that are not aligned with system security needs, particularly during tight reserve conditions or constraint-driven events.

  It is scored low for Victoria because the driver is not state based. Victorian materiality primarily depends on the penetration of price-responsive hyperscale load and how those sites are configured for fast response. The medium-term timeline reflects that materiality increases mainly with adoption and penetration, so it is best managed through disclosure of intended operating modes and scenario testing, rather than being treated as an immediate universal requirement.

5.3.4. Power quality impact including harmonic resonances

Like almost all inverter-based loads, data centres draw energy from the power system in an imperfect manner. This is an inherent result of the high-efficiency switching nature of the power electronic devices used. Great lengths are taken by OEMs and developers to minimise the net impact to the power system to maintain power quality standards. Fluctuations, imbalances and oscillations can still occur, especially where there are clusters of inverter-based loads (including data centres) near each other, or where data centre reticulation networks interact with the UPS equipment and the grid.

This is a medium risk for the entire NEM with a medium-term timeline.

Power quality refers to how clean and constant the electricity is when it reaches consumers. Good power quality means the voltage stays steady, without sudden or regular drops, spikes or waveform distortions. However, the system and its end-users are non-ideal, meaning that the voltage supplied to consumers is seldom a perfect, unchanging sinusoidal wave. Aspects of power quality to be considered include:

- voltage fluctuations
- voltage imbalances between phases
- voltage and current harmonic distortion
- flicker (changes in voltage noticeable to the human eye through light sources)
- electromagnetic interference.

Poor power quality can stem from many different sources like:

- nearby end-users drawing energy from the grid in a non-linear or pulsating manner
- problems with the network equipment transporting the energy from one place to another
- generators misoperating during production.

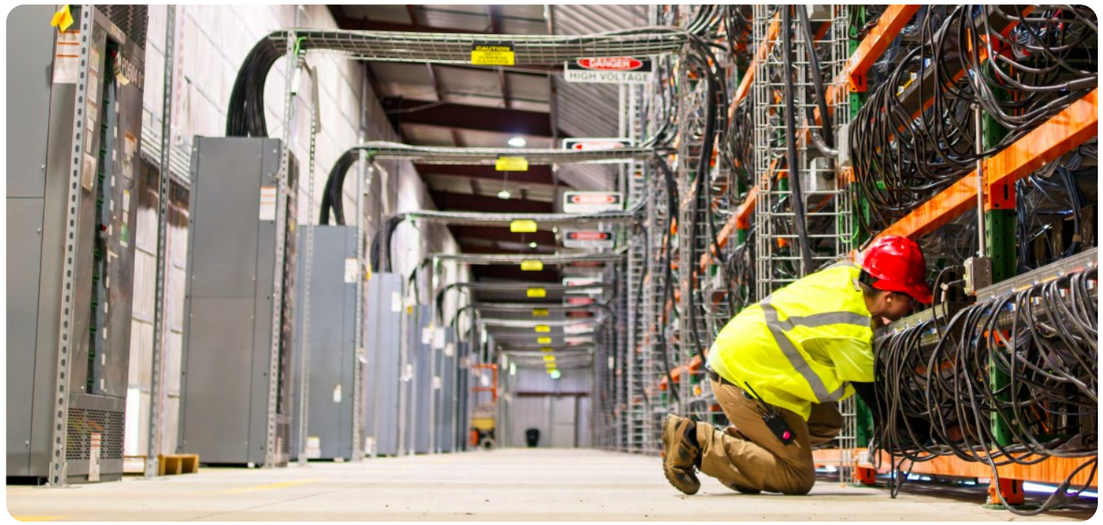
While power quality is subject to strict standards and continuously monitored and reported to regulators by network operators, real-time intervention on poor power quality is generally infeasible, requiring significant amounts of time, analysis and in-field investigations to identify and resolve.

Major loads, which may be contributors to poor power quality (e.g. arc furnaces) or sensitive to poor power quality (IT load), are expected to have power quality improvement facilities in place to minimise the impact to the grid and its customers (former), or have 'buffers' supplying their load where the sensitivities are greater than the power quality standards network operators are bound to maintain (latter).

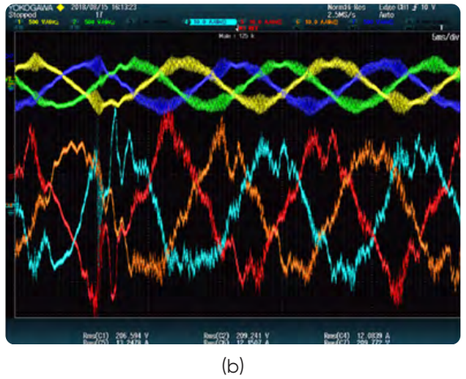
In normal operation, it is first assumed that the IT load will remain relatively constant and present a near-unity power factor to the grid. This means that, most of the time, the server load itself should not cause adverse power quality impacts.

Even when the IT load is steady, the power electronic equipment that serves it produces harmonic emissions. These are extra current components at frequencies at multiples of the grid frequency - for example, 150 Hz, 250 Hz, etc. on a 50 Hz system. Under normal conditions, these emissions are limited by design and standards and the network absorbs them with modest distortion of the voltage waveform. Harmonic resonance is different. It occurs when the inductances and capacitances in the cables, transformers and filters line up so that the system naturally "rings" at a particular frequency. In that case, even relatively small harmonic emissions from the data centre can be amplified into large oscillations in current and voltage at specific frequencies.

Such behaviour has already been observed in operational facilities. For example, in 2017 a very similar resonance phenomenon was recorded in several Meta data centres. **Figure 22(a)** below shows representative current and voltage measurements at the tap box of a server rack, where a slow 11 Hz oscillation is visible in the envelope of both current and voltage and Fourier analysis shows strong components around 49 Hz and 71 Hz on all three phases. In other data centres, high-frequency resonances in the 5–10 kHz range were also observed, as shown in **Figure 22(b).** These examples show that the key issue is not only how much harmonic emission a data centre produces, but how those emissions interact with the surrounding network and its natural resonances, both at low frequencies and in the kilohertz range.



(a)



(b)

▲ **Figure 22:** Measured resonances in data centre power systems: (a) low-frequency resonance and (b) high-frequency resonance[78]

However, if the IT load varies significantly in a short time, it can introduce its own power quality emissions in addition to the resonance issue.

Risk factor assessment

- **Relevance to the NEM:** Medium
- **Relevance to VIC**: Medium
- **Timeline:** Medium-term
- **Reasoning:** Power quality and resonance risks are credible but strongly depend on the context. The most severe outcomes arise from network interactions and configuration rather than emissions magnitude alone.

  This is scored medium because although potential risks are usually "designed-out" at the development stage, triggering such circumstances may not be entirely due to elements under the data centre's control. Consequences can include sustained distortion, nuisance tripping, equipment stress and in adverse resonant conditions, loss of key elements with system security implications. These issues are typically slow to diagnose and resolve once the equipment is in service. The timeline is medium-term because the risk is not universally dominant for every connection, but it can become effectively short-term where screening indicates elevated sensitivity.

78. J. Sun, M. Xu, M. Cespedes and M. Kauffman, "Data Center Power System Stability — Part I: Power Supply Impedance Modeling," in CSEE Journal of Power and Energy Systems, vol. 8, no. 2, pp. 403–419, March 2022

5.3.5. The risk of frequency instability

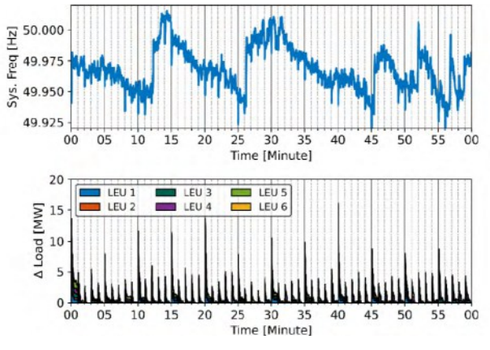
Rapid ramp rates and a lack of clear requirements concerning fault-ride through for large loads create conditions where data centre load disconnections could lead to large fluctuations in the system frequency.

Coincidentally, there is increasingly limited visibility of large loads to the dispatch engine as more proponents seek to connect at distribution level, reducing the ability of the system operator to predict and plan for contingencies. These factors, along with the planned retirement of coal-fired generation lead to the risk of frequency instability. This in turn poses a significant risk to the system operator's ability to plan and operate the system safely in credible contingency conditions.

This is a medium risk for the NEM and high risk for Victoria with a short-term timeline.

Large-scale, almost instant data centre disconnections (i.e. mass transfers to backup) create a positive contingency (generation exceeds load) so frequency rises quickly and regulation/primary controls must arrest and return it to nominal. A recent US Eastern Interconnection event illustrates the scale:

- Approximately 1,500 MW of voltage-sensitive data centre load reduced within 82 seconds during a reclosing sequence, pushing frequency to about 60.05 Hz before settling back to 60 Hz in four minutes.[79] In a smaller system or lower-inertia operating conditions, the same size of coincident load step or ramp can drive a higher rate of change of frequency (RoCoF) and deeper frequency excursions, effectively increasing the minimum inertia (or equivalent fast frequency response) needed to maintain secure frequency performance.



▲ **Figure 23:** Impact of IT load variations on system frequency[80]

Even without tripping, coordinated seconds-scale workload cycling from AI/HPC clusters widens the standard deviation of frequency and increases automatic generation control (AGC) duty. This is because balancing processes are tuned for many small, uncorrelated variations, not for synchronous swings or step-changes of hundreds of megawatts. For example, **Figure 23** below shows the impact of IT load variation on system frequency in an all-island power system. As shown, during the 60-minute all-island test, system frequency drifted around 49.95–50.0 Hz due to cyclic IT load variations.

The sharp 15–20 MW load steps visible in the figure arise from normal operation of six large energy users (LEU1–LEU6), each corresponding to an individual data centre. Their workload-driven power ramps occur naturally in response to IT processes and operational decisions. The resulting frequency trace therefore illustrates how real data centre behaviour, even without any trips or protection actions, can drive measurable short-term frequency deviations and increase the duty on frequency control and reserve provision.

Risk factor assessment

- **Relevance to the NEM:** Medium
- **Relevance to VIC**: High
- **Timeline:** Short-term
- **Reasoning:** This item captures the frequency consequences of the higher-ranked risks in **Table 8** (disturbance transfer/recovery and rapid MW variability), rather than introducing a separate mechanism. Large, coincident MW changes, whether from transfer-to-backup and recovery or from normal-operation workload cycling, increase the duty on regulation and reserves and can materially influence contingency sizing and operational security. Currently in Victoria, the largest allowable contingency is less than in other states - there is no resecuring reserve to manage large MW swings and there are no SIPS in place.

  Given the scale of prospective hyperscale connections, these frequency impacts are relevant in the near term but they are best managed by prioritising the underlying drivers (ride-through, recovery expectations, credible variability and ramp envelopes) rather than treating "frequency instability" as a standalone primary risk.

79. North American Electric Reliability Corporation, Incident Review—Considering Simultaneous Voltage-Sensitive Load Reductions, Jan 2025.
80. EirGrid, Experience with large load interconnection, March 2025

5.3.6. Forced oscillations

Power electronic control algorithms and faulty equipment have the potential to cause persistent oscillations in the system frequency independent of grid conditions, which can lead to resonances. While the nature of such oscillations caused by inverter-based resources has been studied extensively, those caused by data centres are currently not well understood.

This is a medium-relevance, medium-term risk for the entire NEM.

Variations in data centre IT load profile can potentially create periodic low-frequency power oscillations up to 3 Hz, which are within the natural modes[81] of power system electromechanical oscillations. Recent international incidents show that data centres can also trigger higher-frequency control-induced oscillations in the 10–30 Hz range caused by power electronic controls rather than IT load variations. In addition to control algorithms operating as intended, forced oscillations can also originate from faulty or degraded equipment - for example, mis-tuned controllers or firmware defects in inverter or UPS systems. Similar behaviour was observed at several IBR installations and some data centre projects, where equipment faults produced persistent oscillations even under nominally steady IT loading.

Forced oscillations occur when a load or generation source introduces periodic disturbances independent of grid conditions, at frequencies near these natural modes. These oscillations can propagate across the system, potentially leading to resonances which result in tripping of generators, load or network elements on self-protection. Worst case scenarios include cascaded tripping of a generating plant, causing supply shortfalls, blackouts, network asset or generator damage.

Importantly, the spiking or pulsating power demand of a data centre or cryptocurrency mining operation could unintentionally excite natural oscillatory modes, especially if the periodic load changes are driven by internal control algorithms operating near the system's eigenfrequencies.[82] The 23 Hz active-power oscillation observed at a large ERCOT campus in 2024 and the approximately 14.7 Hz voltage oscillations reported by Dominion Energy, are examples where internal controllers and limit cycles within data centre equipment created persistent, narrow-band oscillations that propagated into the surrounding network.

Identifying forced oscillations from general interactions lies in the persistence and independence of oscillations from dynamic feedback mechanisms. While general interactions typically involve mutual influences between grid dynamics and load or generation controls, forced oscillations stem from periodic inputs unrelated to the grid's immediate state. Accurately identifying and mitigating these oscillations is crucial for system stability, particularly in systems with increasing penetration of fast-responding, non-traditional loads.

Similar control-induced forced oscillations and sustained sub-synchronous voltage oscillations were also observed in the West Murray Zone of the NEM recently, driven by interactions between inverter controls and low system strength conditions.

For inverter-based resources, this type of behaviour is now a relatively well understood problem. Over the past six to seven years, it was the subject of extensive study with dedicated models, screening methods and investigative tools and it is often, though not always, exacerbated by low system strength conditions.

By comparison, forced oscillations associated with data centres are a much newer topic and the extent of the differences and contributing factors is not yet well understood relative to the existing IBR knowledge base. Nevertheless, the technical community can leverage many lessons learnt from IBR investigations, including pre-emptive analysis and root-cause investigations.

Risk factor assessment

- **Relevance to the NEM:** Medium
- **Relevance to VIC**: Medium
- **Timeline:** Medium-term
- **Reasoning:** Forced oscillations were reported internationally in connection with large power-electronic loads and may plausibly arise from workload-driven cycling, equipment malfunction or control interactions across site-level systems.

  Although the extent to which these mechanisms are material for Australian data centre connections is not yet established, Victoria has seen examples of power system oscillations driven by inverter-based equipment during low system strength, with no evidence that data centres are immune to such scenarios. Hence, this remains a medium risk until further informed by targeted investigations using fit-for-purpose dynamic representations and high-resolution monitoring of new data centre installations.

81. A natural mode is a natural resonant frequency and damping ratio that a power system may have due its inherent topology and components.
82. An eigenfrequency is a natural frequency of oscillation of the power system.

5.3.7. The risk of exciting torsional modes of oscillations

International transmission operators warned that data centres could trigger sub-synchronous (below 50 Hz) oscillations, potentially leading to shaft damage in synchronous machines. This risk is significantly more than IBRS due to the potential for data centres being located closer to traditional power stations (increasing the risk of equipment damage), the potential for slow, pulsating power draw from the power system and the deployment of synchronous condensers with heavy flywheels for simultaneous system strength and inertia provision.

This risk requires further site-specific investigations before it can be appropriately classified.

ERCOT and NERC raised concerns about the risk of sub-synchronous (i.e. below 50 Hz) power system oscillations caused by data centres through the excitation of torsional modes[83] in nearby thermal power stations. This risk is considered more significant than that posed by IBRs, due to the data centres being closer to areas with high concentrations of synchronous generators. While proximity between large data centres and synchronous plant increases the likelihood of exciting sub-synchronous torsional modes, the risk is not confined to co-located assets because these oscillations are low frequency (below 50 Hz) and can propagate over wide areas with far less attenuation than higher-frequency phenomena such as harmonics.

Risk factor assessment

- **Relevance to the NEM:** TBD (further investigation required)
- **Relevance to VIC**: TBD (further investigation required)
- **Timeline:** TBD (further investigation required)
- **Reasoning:** International experience raised torsional interaction and torsional mode excitation as a potential risk in systems with nearby synchronous plant under certain operating conditions. The materiality and triggering conditions for NEM/VIC data centre connections are not yet established and should be assessed through targeted investigation using fit-for-purpose dynamic representations and high-resolution measurements, rather than assumed from generic load behaviour.

83. Torsional modes are the natural resonant frequencies of large spinning mechanical masses, such as generator turbine shafts.

6 A data centre enablement framework

Key messages

- The data centre behaviours explored in this paper are relatively new to the NEM and differ from traditional loads.
- We are still developing robust planning and operational tools to model and manage inverter-based loads. Specifically:
  - The industry does not currently have a suite of representative, validated models of data centre behaviour or consistent real-time monitoring of how these facilities actually perform once connected.
  - Technical requirements for inverter-based loads are either not fully specified or are inconsistently applied across the NEM. Compliance with intended performance is not consistently monitored.
  - There are insufficient processes to collaboratively learn from new data centre developments or to continuously improve how data centre integrations are being handled.
- There are four areas in which the electricity sector can respond to data centres as they grow and evolve: connections, planning, operations and engagement.
- The four areas form the basis of our data centre enablement framework, which outlines seven near-term actions (0-2 years period) to integrate data centres while protecting the power system.
- For each action, we have identified what reform is required, current progress and how it relates to our assessment in Chapter 5.

This chapter proposes a data centre enablement framework that brings insights from previous chapters together in a set of near-term priority actions for the power and data centre industries to collaborate on.

6.1. Why we need an enablement framework

Data centre technical performance differs to traditional loads, requiring new ways to manage their connection and operation within our power system

As outlined in Chapter 5, data centres present very different power system behaviours to traditional loads, including fast MW variability, uncertain ramping profiles during normal operation and sensitivity to disturbance risks. Potential impacts include an undefined ride-through capability for common power system faults, rapid active power ramping leading to frequency control challenges, power quality issues and risk of forced oscillations.

We also know data centre development can emerge quickly in specific regions and scale rapidly as multiple proponents compete to connect quickly to secure sufficient grid capacity at a location. While individual connections appear manageable in isolation, the aggregate effect of multiple non-uniform data centre installations in an electrically nearby area can exceed what the network and the power system were designed to accommodate. These clustering and rapid uptake effects, if not appropriately managed, can increase the aggregate effect of technical issues turning localised events into material system events.

The NEM is still developing robust tools or processes to model or manage data centres

The data centre behaviours explored in this paper are relatively new to the NEM. As covered in Chapter 3, the power system was built to support large industrial loads, such as smelters and refineries. Therefore, it should be no surprise that the NEM is still developing the necessary planning and operational tools to model and manage inverter-based loads. This plays out in a few ways:

- **Unknown performance**

  The industry does not currently have a suite of representative, validated models of data centre behaviour, nor does it have consistent real-time monitoring of how these facilities perform once connected.

  Without accurate models and operational data, planners and operators cannot effectively assess dynamic interactions, system strength impacts or the cumulative effects of many similar connections. This lack of understanding inevitably leads to conservative assumptions in some areas and blind spots that can miss key behaviours of power-electronic front ends and site controls. Neither supports efficient investment or secure operation.

- **Undefined management requirements**

  Outside of Victorian transmission connections, requirement for data centre behaviour in the Australian power system are still being defined. Technical requirements being proposed either do not cover all aspects of pressing risk identified in this paper or are at risk of being inconsistently applied across the NEM. This includes between network service providers within a single region. Compliance with intended performance is not consistently monitored and approaches to optimise network planning decisions to account for "size creep" are still evolving, particularly for distribution connected plant.

  It is important that generator-oriented compliance frameworks, study processes and performance obligations are not applied to data centres by default. Data centres are not generators and their operational philosophy, controls and protection logic are materially different, so adopting inverter-based resource-oriented access standards as a proxy can result in technical requirements and study approaches that are not suitable for data centres.

- **Collaborative processes are still maturing and not publicly visible**

  Processes to collaboratively learn about new data centre design and operational capabilities or to continuously improve how data centre integrations are being handled - are still developing. Network service providers, system operators, data centre developers, equipment manufacturers and commissioners all hold pieces of the puzzle. More can be done to leverage existing collaborative processes to coordinate insights, share operational experience or refine technical management approaches.

There are four areas where our electricity sector can respond to the data centre industry as it grows and evolves

We propose the power system and data centre industries work together on a proactive, coordinated approach to accommodate data centres - this supports power system security and Australia's continued digital and economic growth. The four areas:

1 Connections

Fit-for-purpose requirements

Establishing fit-for-purpose NEM-wide performance requirements for transmission and distribution-connected inverter-based loads enables data centres to deliver predictable behaviours that support system security, while accelerating the overall connection process. Clear expectations around fault ride-through performance, acceptable active power ramp rates and oscillatory behaviour reduce uncertainty and prevents adverse interactions as penetration increases.

Modelling and predictability

Consistent and robust connection modelling requirements are essential to improving understanding before assets connect, as it is far cheaper to identify and remediate issues before construction than after operation begins. Requiring high-quality, representative models enables network service providers to assess risks accurately and proportionately, particularly where multiple data centres may interact.

2 Planning

Network plans

Using state transmission plans to proactively guide data centre development addresses the collective risk. By signalling where the network can efficiently support large new loads, these plans can help steer investment to appropriate locations, reducing congestion, system strength challenges and inefficient network upgrades.

Transparency and reporting

Furthermore, collecting and publishing load connection information improves transparency and system-wide awareness of how fast and where change is occurring. This visibility is a prerequisite for network planners and operators to anticipate emerging risks rather than reacting after problems materialise.

3 Operations

Monitoring and reviewing operational mechanisms

Improved real-time visibility of inverter-based loads addresses operational uncertainty. Understanding how data centres are actually behaving in real time and in high definition creates the foundation for secure system operation, as these loads become a dominant feature of demand and allow for validation of the models used for future connection and planning studies.

Exploring operating implications, including potential new mechanisms, required to manage a future with a high penetration of large loads – for example, outage planning and FCAS contingency procurement.

4 Engagement

Open collaboration

Leverage existing technical working groups to collaborate on foundational integration issues. This includes encouraging shared learning, coordinated evolution of standards and continuous improvement as technology and system conditions evolve.

These areas have formed the basis of our data centre enablement framework, which identifies a practical set of near-term actions.

6.2. The data centre enablement framework

This section outlines seven near-term actions (0 to 2 years) to integrate data centres while protecting the power system. Here's an overview of the enablement framework. Further detail is provided in the subsections below.

Providing data centres with a coherent and timely pathway to grid connection	**Action 1** Establish fit-for-purpose NEM-wide performance requirements for transmission and distribution-connected inverter-based loads **Action 2** Establish robust NEM connection study and model requirements for inverter-based loads
Coordinating the efficient and safe development of data centres	**Action 3** Use state transmission plans to proactively drive data centre development to areas where the network can best support them **Action 4** Collect and publish load connections information to better understand the pace of change and implications for the power system
Operating the power system with a high concentration of inverter-based loads	**Action 5** Improve real time visibility and control of inverter-based loads **Action 6** Investigate operational planning implications in a system heavily loaded with data centres
Improving our understanding of data centres as they evolve	**Action 7** Collaborate on foundational data centre integration issues and keep pace with evolving data centre practices

We encourage further conversation about this data centre enablement framework and are open to exploring additional actions or constructive changes that may support its intent.

6.2.1. Providing data centres with a coherent and timely pathway to grid connection

Purpose: Establish fit-for-purpose performance, study and model requirements that reduce "project-by-project reinvention", focus on the real-world behaviours, operating envelopes and fault ride-through profiles of data centres that reflect materiality of the data centre to the power system at a particular connection point.

6.2.1.1. Action 1: Establish fit-for-purpose NEM-wide performance requirements for transmission and distribution-connected inverter-based loads

Relates to the Chapter 5 Risk Assessment(s):

- 5.2.2 Defining fit-for-purpose technical requirements and standards
- 5.3.2 Additional concerns on lack of fault ride-through
- 5.3.4 Power quality impact including harmonic resonances
- 5.3.6 Forced oscillations

Technical requirements for connection under NER Schedule 5.3 and associated guidance should be updated to reflect the real-world behaviour and performance of data centre power-electronic components.

Defining a new class of load (i.e. large 'inverter-based load') would draw focus towards integration challenges specific to data centres, recognising the current NER provisions were drafted for traditional loads that do not exhibit the same behaviour.

Table 10 below takes an evidence-based approach to identify the scope of potential performance concepts that industry and policy makers should consider to safely integrate transmission and distribution-connected inverter-based loads.

It leverages Bespoke Energy's recent experience supporting NEM data centre connection applications and modelling of control systems to:

- address the most pressing power system impacts in the NEM assessed in Chapter 5 - performance capability that reflects and responds to the behaviour of data centre power-electronic components and their different workloads (e.g. fault ride through capability, active power ramping)
- address performance elements that Chapter 5 identifies are less pressing, but represent good practice in a changing power system (e.g. oscillation detection)
- align with known (or reasonably achievable) capabilities of data centres and their OEMs and avoid requirements that could drive significant delay to connection approval. For example, requirements for data centres to smooth UPS behaviour or avoid harmonic resonance have been avoided.

Table 10 is intended to offer certainty to data centre developers about the types of performance concepts required. Performance concepts should be flexible to project specific factors, such as connection voltage, data centre size and external network including nearby connected plants and customers.

Performance requirement	Descriptions
Fault ride through disturbances	• Must ride through credible network faults at the point of connection for a time equal or greater than the primary protection clearance time at the associated point of connection voltage. • Avoid protection systems that operate in response to multiple successive faults.
Post-fault behaviour	• Reconnection of IBL to commence within a defined timeframe following a return to voltage to normal range. • Active and reactive power must recover to pre-fault levels within defined time limits.
Frequency stability	• Operate continuously between 49-51Hz (i.e. within normal operating band). • Withstand rate of change of frequency (RoCoF) events (e.g. +/-2 to 4 Hz subject to study) without tripping. • Frequency dependent controls must not induce additional oscillations.
Voltage stability and reactive power	• Remain connected within defined steady-state voltage range. • Provide reactive support or operate at near-unity power factor. • Ride through rapid phase angle shifts.
Active power ramping	• Active power ramp-up / ramp-down limited to agreed MW(s). • Start up, shutdown and step-load changes must be managed to prevent voltage flickers. • Data centres with UPSs be capable of reducing rapid active power changes and have this functionality enabled.
Power quality	• Data centre facility must be designed, operated and controlled so its connection to the power system does not adversely impact power quality for other network users. • Voltage fluctuation: the data centre must manage normal operations, start-up, shutdown, load steps, UPS transfers and fault recovery to limit voltage fluctuation at the connection point. Step changes in active and reactive power must be controlled to avoid excessive voltage deviations. • Voltage unbalance: the data centre must not cause or contribute to voltage imbalance at the connection point beyond agreed planning and operational limits. • Voltage and current harmonic distortion must comply with AS/NZS 61000 limits or site-specific harmonic limits determined through connection studies. • Electromagnetic Interference (EMI): the data centre facility must not generate conducted or radiated EMI.
Oscillation mitigation	• Control system must be tuned to avoid forced oscillation and harmonic amplification. • Active participation in oscillatory events must be monitored and the NSP informed (warning).
System strength requirements	• Must meet minimum short circuit ratio (SCR) threshold or implement mitigation solution.

▲ **Table 10:** Scope of potential performance concepts to safely integrate transmission and distribution-connected inverter-based loads in addition to Schedule 5.3 of the NER

Table 11 compares Bespoke Energy's suggested performance concepts in **Table 10** with performance requirements proposed in the AEMC's *Improving the NEM access standards – Package 2* Draft Determination[84] and VicGrid's *Data Centre Connections Guideline*.

The scope of performance requirements identified in the AEMC's draft rule and VicGrid's Guideline, broadly align with Bespoke Energy's suggestions. Differing approaches can be seen with respect to ramp rate limits and start-up and shutdown controls. Bespoke Energy's view is that its proposed minimum performance requirements are practically achievable and reasonably required to protect the power system.

Type of performance requirements		Bespoke Energy proposal	AEMC draft rule	VicGrid guideline
Applicability	Large IBL threshold	✓ ≥ 30 MW	✓ ≥ 30 MW	⚠ Implicit (project by project)
	Tiered framework	✓ Tier 1 (<30MW) Tier 2 (≥30 MW)	✓ Tier 1 (<30MW) Tier 2 (≥30 MW)	✗ No tiering
Fault ride through disturbances	Voltage ride-through	✓ Required	✓ Required	✓ Required
	Post-fault active power recovery	✓ Within defined time	✓ 90% within 500ms (auto), 1s (min)	✓ 90% within ~500ms
	Frequency ride-through	✓ Required	✓ Required	✓ Required
	Vector Shift Protection	✓ Required	✓ Required	✓ Required
	Multi-fault ride through	✓ Required	⚠ Implicit[85]	⚠ Case-by-case
Active power ramping	Ramping rate limits	✓ Required	⚠ NSP discretion	⚠ Case-by-case
	UPS-based smoothing	⚠ Encouraged	⚠ Supported	⚠ Encouraged
	Start-up/shutdown control	✓ Required	⚠ Implicit	✓ Required
Power quality	Harmonic limits	✓ Required	✓ Required	✓ Required
	Flicker limits	✓ Required	✓ Required	✓ Required
	Voltage unbalance	✓ Required	✓ Required	✓ Required
	EMI	✓ Required	✗ Not explicit	✓ Required
Oscillation	Avoid forced oscillation	✓ Required	✓ Instability standard ≥ 30 MW	✓ Required
	Prevent amplification and control system tuning	✓ Required	⚠ Case-by-case	✓ Required
Oscillation	SCR minimum	✓ ≥3	⚠ ≥3 only for ≥30 MW	⚠ Typically ≥3 Possibly applied below 30MW

▲ **Table 11:** Comparison of Bespoke Energy's suggested performance concepts against other existing requirements

84. AEMC, Improving the NEM access standards – Package 2 Draft Determination, March 2026
85. The AEMC's draft rule stipulates that IBL must not have protection systems that operate based solely on the number of faults that occur during a period of time.

Policymakers should carefully consider the application of access standards across distribution and transmission connected data centres for plants 30 MW and above. AEMO presented NEM-specific modelling results that demonstrate IBL sites less than 40 MW behave coherently rather than independently. It identified that the aggregate response gives rise to cumulative power system impacts that can match or exceed severity of larger individual connections.[86]

AusNet is particularly concerned with the simultaneous disconnection of multiple IBLs between 30-100 MW following a disturbance. For example, the disconnection of three 100 MW (or ten 30 MW) data centres in response to a common fault ride through limitation would in aggregate represent a 300 MW loss; this is half the size of Victoria's largest contingency.

For detailed thoughts on the tiered application of access standards to IBLs, see our submission to the AEMC *Improving the NEM access standards – Package 2* Draft Determination.[87]

What does cumulative impact mean?

Cumulative impact refers to the risk that multiple geographically close data centres or multiple halls within a campus, respond in a similar way to the same initiating event because they share similar control philosophies and disturbance thresholds. In this case, what is electrically a single network event can translate into a materially larger aggregate MW change because the sites behave coherently rather than independently.

In Victoria, we are seeing this play out today with multiple 150 MW+ data centre projects seeking connection at distribution and transmission level within the same area (see case studies in Section 1.2.4).

This risk can also extend beyond data centres themselves to correlated behaviour with nearby inverter-based devices. AEMO explicitly flagged the potential for sympathetic tripping of large inverter-based loads located close to major distributed PV (DPV) clusters in Sydney and Melbourne, which is a practical example of how cumulative inverter behaviour on shared corridors can increase the effective contingency size and complicate predictability.

Implementation:

Reform required	**Regulatory** Rule change establishing fit-for-purpose technical connection requirements for transmission and distribution inverter-based loads in the NER. Interim data centre connection guidelines by AEMO and network service providers.
Progress	**Underway** AEMC rule change and AEMO interim guidelines are currently in development and could give full effect to Action 1. For further information see **Appendix B**.

86. AEMC, Improving the NEM access standards – Package 2 Draft Determination, March 2026
87. AusNet, Submission to the Improving the NEM access standards – Package 2 Draft Determination, May 2026

6.2.1.2. Action 2: Establish robust NEM connection study and model requirements for inverter-based loads

Relates to the Chapter 5 Risk Assessment(s):

- 5.2.3 Limited representation of dynamic behaviours
- 5.2.4 Rapid connection timelines
- 5.2.6 Insufficient compliance enforcement
- 5.2.8 Capacity creep

Technical guidance should be developed to outline a set of study requirements, model requirements and associated processes that credibly characterise the performance of a data centres' power-electronic components.

Study and model guidance should align with the revised inverter-based load performance requirements in Action 1 and assist developers and OEMs develop and submit credible power system models of their data centre equipment (i.e. dynamic representation or where this is not practical, simplified demand profiles bound to credible assumptions).

A key part of the guidance should be clarifying the role of NSPs and AEMO to assist the developer. For example:

- The information required for proponents to submit compliant models and studies for assessment.
- The expected model and study program and process, including details of the NSP assessment process and potential circumstances in which additional information or studies may be required.

Table 12 outlines Bespoke Energy's view of key single-machine infinite bus study requirements for consideration.

Further industry consultation is required to inform the scenarios where it should be mandatory or optional for developers to:

1) submit a model (e.g. PSS/E, PSCAD)

2) complete studies to demonstrate performance.

This will need to balance several factors:

- The time and cost for developers and capabilities of their OEMs to develop requested models and undertake requested studies.
- The capabilities of NSPs to validate submitted models and study results and where necessary, conduct their own.
- The power system integrity risks from NSPs not having access to a particular model or study result.

Performance requirement	Key study	Tools / models
Fault ride through disturbances	Dynamic RMS fault ride-through studies at varying operating points and system strength levels. Verify: • correct FRT triggering and protection operation • restoration or reconnection behaviour, including ramp commencement and ramping behaviour if tripped • ride-through of voltage dips/swells and multiple consecutive faults without disconnection • dynamic EMT fault ride-through study. Repeated for items as above.	PSS/E RMS dynamic model PSCAD EMT model
Frequency stability	• Frequency disturbance and rate of change of frequency (RoCoF) study to verify continuous operation at 49-51Hz and tolerance to RoCoF.	PSS/E RMS dynamic model PSCAD EMT model
Voltage stability and reactive power	Reactive control dynamic studies (if applicable): • Setpoint-induced changes. • Grid-induced changes.	PowerFactory frequency domain model
Power quality	Harmonic emission compliance study.	PowerFactory frequency domain model
Oscillation mitigation	EMT oscillation study to assess the control interaction*	PSCAD EMT model
System strength requirements	EMT study to assess performance under weak grid condition	PSCAD EMT model

▲ **Table 12:** Scope of potential study requirements to safely integrate transmission and distribution-connected inverter-based loads

*Small-signal stability study with associated SSAT model to assess control tuning, forced oscillation risk and torsional interaction may be required in the future.

Implementation:

Reform required

Regulatory

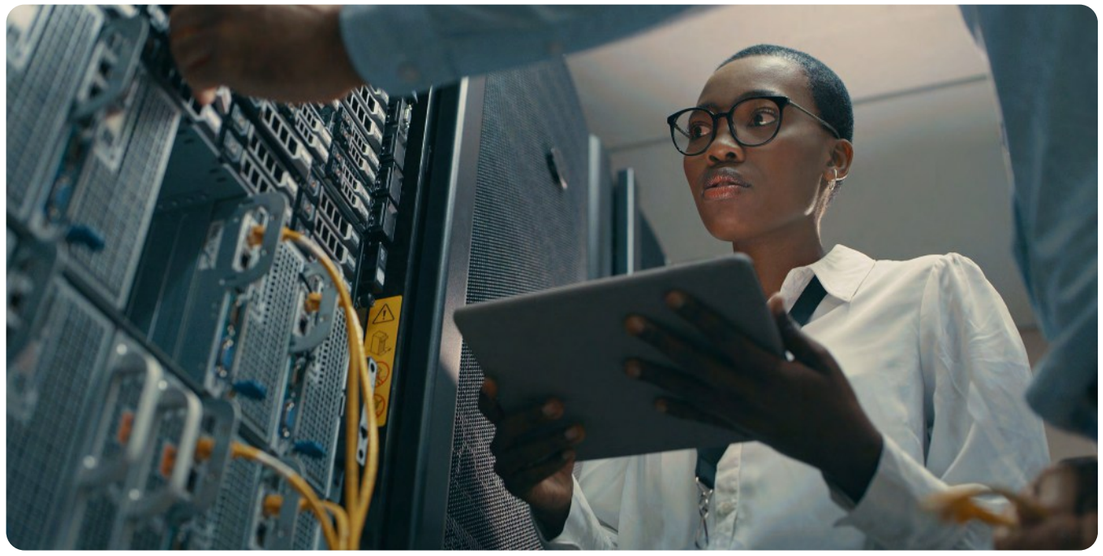
Rule change establishing fit-for-purpose technical connection requirements for transmission and distribution inverter-based loads in the NER.

Interim data centre connection guidelines by AEMO and network service providers.

Progress

Underway

AEMC rule change and AEMO interim guidelines are currently in development and could give full effect to Action 1. For further information see **Appendix B**.



6.2.2. Coordinating the efficient and safe development of data centres

Purpose: Proactively and transparently coordinate data centre connections with electricity planning decisions to minimise total system costs and protect system integrity. Leverage TNSP capability to minimise time and cost of connection for data centre development.

6.2.2.1. Action 3: Use state transmission plans to proactively drive data centre development to areas where the network can best support them

Relates to the Chapter 5 Risk Assessment(s):

- 5.2.1 Coordination between stakeholders
- 5.2.4 Rapid connection timelines
- 5.2.7 Lack of forecasting and predictability

TNSPs should use state transmission plans to detail the data centre development that can be accommodated within their respective region and encourage projects to specific sites where the network is best placed to support them.

There are several interrelated problems that have informed this action:

- The total volume of data centre connection interest being received by NSPs is beyond what existing transmission and distribution networks and plans support (18 GW in Victoria alone). While not all will reach financial close, the timeframes to commission network upgrades is much longer than for data centre facilities, mandating a proactive response.
- The specific location of this interest is not optimised to align with the most efficient and secure outcome for the power system. For data centre developers this may mean the timeframes, costs and risks of connecting at the nominated site may be substantially greater than expected, undermining investment confidence. For other customers, data centre interest in the wrong locations can erode capacity for general load growth (e.g. electrification of households). For network planners, there is a risk that solutions are reactionary to data centre connection applications and individual NSP plans, rather than optimised to minimise total system costs and maintain system integrity.

There is an opportunity to proactively use state transmission plans to address these 'power coordination' challenges:

- **Forming credible scenarios for data centre development.**

  The update to existing scenarios (e.g. AEMO's step change scenario) should carefully consider the size, timing and location of development over its planning horizon.

  For example, whether scenarios should be informed by real-world development expectations and trends (e.g. clustering of load around urban availability zones, accuracy of forecasts to determine load genuinely likely to proceed).

- **Sharing robust analysis about the extent to which data centre development under these scenarios can be accommodated and where it may become a problem due to generation, network and system security limitations.**

  For example, facilitating data centre development at one location may require significant network investment at transmission and distribution level or both. This may include solutions to relieve technical challenges (i.e. thermal capacity, voltage, system strength) or physical expansion limitations (i.e. space for new transformers, connection bays).

- **Signalling locations where data centre development can be facilitated, optimising developer and planner-initiated augmentations.**

  We see value in state transmission plans outlining a long term expansion pathway (i.e. generation, storage, network) to facilitate data centre growth under its scenarios, including an indicative quantum of connections that can be reasonably facilitated at distribution and transmission level across the state.

  This should offer a consolidated view on the optimal timing of developer-initiated augmentations funded by data centre proponents through NSP connection processes (e.g. developer funded terminal stations) and planner-initiated augmentations (e.g. shared terminal station and line upgrades). It may also include other system security related investments driven by the connection of inverter-based loads (e.g. system strength, inertia requirements).

Our view is that a TNSP-led approach is critical to the success of this action. TNSPs have the accountability, capability and planning interfaces to make the right long term planning decisions. As the transmission system planner, TNSPs are the only party that can assess and resolve cumulative impacts from significant data centre load connecting at both distribution and transmission level. This includes making calls about where generation can come from and resolving transmission and system limitations binding a connected plant. TNSPs are also the only party that directly interfaces with all DNSPs in their region. They are best placed to seek inputs from DNSPs (e.g. request visibility of distribution constraints and needs on their respective networks) and coordinate system planning.

Could data centre precincts be a better pathway to coordinate development?

We considered several planning philosophies when considering how to proactively coordinate data centre development to align with network capabilities. These fall into three conceptual options defined in **Figure 24** below.

Option 1 (market-led) is effectively the status quo, where location decisions are driven by proponents via the connection process and NSPs planning decisions are reactive to their location decisions. Option 3 (precincts model), where the TNSP centrally coordinates development (generation, load, network, land and planning approvals etc). Data centre developers are encouraged to apply for connection within specific locations via access schemes, competing for capacity on the TNSPs terms (e.g. hosting capacity limits within permitted areas of development). Option 2 (planner guided) sits in between and is our preferred approach, as described above. It leverages TNSP transmission plans to signal where capacity is available, while providing developers the opportunity to choose a location that minimises connection risk.

Option 1: Market-led	**Option 2: Planner-guided** (preferred)	**Option 3 Precincts model**
NSPs reacts to data centre developers site selection preferences received via connection application process. For example, availability of land, timely planning approvals, proximity to availability zone.	TNSPs signal to data centre developers to locate where data centre development can be facilitated. This includes signalling its pathway to facilitate data centre growth – cognisant of reducing total system cost and developer preferences.	TNSPs permit data centre developers to locate within specific locations. This includes centrally planning 'precincts' to facilitate data centre growth.

▲ **Figure 24:** Overview of network planning philosophies to coordinate data centre development

While Option 3 may represent an option most likely to minimise total system costs and protect system integrity, the timeframes required to centrally coordinate data centre growth via precinct (e.g. timely sequencing of network generation and load and associated planning and delivery processes) may slow development. It is expected that Option 2 will offer greater speed to market by allowing developers to efficiently lead data centre development and delivery activities, supported by clear signals about where to locate.

Implementation:

Reform required	**Planning** Proactively use upcoming state transmission plans to drive TNSP coordination of data centre development (e.g. 2027 Victorian Transmission Plan).
Progress	**Exploratory** VicGrid's Draft 2026 Victorian Transmission Plan Guidelines are exploring Victorian electricity system investment needs based on updated data centre demand forecasts that consider locational factors. VicGrid's Draft 2026 Victorian Transmission Plan Guidelines are exploring Victorian electricity system investment needs based on updated data centre demand forecasts that consider locational factors.[88]

88. VicGrid, Draft 2026 VTP Guidelines, May 2026

6.2.2.2. Action 4: Collect and publish load connections information to better understand the pace of change and implications for the power system

Relates to the Chapter 5 Risk Assessment(s):

- 5.2.1 Coordination between stakeholders
- 5.2.4 Rapid connection timelines
- 5.2.7 Lack of forecasting and predictability

Data collection and reporting mechanisms that provide timely and accurate information on existing and proposed generation and storage projects, should be replicated for inverter-based loads.

This recognises that basic information about inverter-based loads is likely to:

1) assist industry understanding of evolving power system dynamics which influence planning, connections and operational decisions

2) informs efficient commercial and operational decisions by data centre developers, such as individual project viability.

Table 13 provides an overview of the information resources that could be extended to inverter-based loads. Both replicate existing AEMO resources for generation plant.

Load information page	AEMO maintains information updated quarterly that informs interested parties of the extent and nature of inverter-based loads connected or proposed to be connected in the NEM. Requires NSPs to share key connection information related to data centres in accordance with guidelines (the "load information guidelines"). AEMO consults, publishes and maintains guidelines that set out the content of the information page, process for updating the page, manner, timing and format of information to be provided by TNSPs to AEMO for the purposes of the page. Intention would be to replicate the generation information page, making technology specific adjustments as required.
Connections scorecard	AEMO maintains an information resource that informs interested parties of the volumes of projects progressing through the connection stages and timeframes, updated at least quarterly. The scorecard would continue to include: • progress tracking of project connection milestones • detailed trend analysis on connection volumes and durations • performance monitoring against history. Intention would be to extend existing technology types covered by the existing Connections Scorecard to include inverter-based loads. Consideration could be given to the granularity of information provided. For example, breakdown of outcomes for different data centre types.

▲ **Table 13:** Proposed load connections information resources

We note this action does not seek to introduce new reporting requirements on data centre developers or NSPs but rather make use of existing non-confidential information collected by AEMO. It would complement improvements AEMO has already made to identify and more accurately forecast data centre projects likely to proceed as part of its annual large industry load and electricity standing information request survey exercises.[89]

Implementation:

Reform required	**Regulatory** Rule change introducing obligations on AEMO and NSPs to work together to develop load connection information resources (similar to NER Clause 3.7F).
Progress	**Exploratory** AEMO's Q1 2026 Quarterly Energy Dynamics Report for the first time included insights into transmission data centre connections across the NEM. AEMO is also gathering comprehensive data regarding distribution connections, with the intent to publish this information in the future.[90]

89. AEMO, Electricity Demand Forecasting Methodology, July 2025
90. AEMO, Quarterly Energy Dynamics Q1 2026, April 2026

6.2.3. Operating the power system with a high concentration of inverter-based loads

Purpose: Improve power system operators real-time visibility control of assets and operational planning decisions to prepare for a power system heavily loaded with data centres.

6.2.3.1. Action 5: Improve real time visibility and control of inverter-based loads

Relates to the Chapter 5 Risk Assessment(s):

- 5.2.5 Observability
- 5.2.7 Lack of forecasting and predictability
- 5.3.1 Rapid ramp rates
- 5.3.3 Excessive price responsiveness

Power system operators should explore practical solutions to improve real time visibility and control of transmission and distribution connected inverter-based loads.

TNSPs across the NEM monitor and control their networks to help make sure the bulk power system operates safely and securely. This includes hosting a control room responsible for monitoring network risks, working closely with AEMO to maintain system security (e.g. reconfiguring the network, load shedding) and facilitating access to the network for new connections and maintenance.

As a network operator, we are particularly concerned about situations where:

- The connection of data centres may be allowed to increase aggregate pre-contingent load beyond the available network capacity. For example, the 220 kV Western Metropolitan Loop discussed in Section 1.2.4. If a network trip or peak demand event was to occur in this scenario, power system operators would require clarity on how they would coordinate curtailment of distribution and transmission connected load to manage upstream network constraints and dispatch.

  We expect the preferred solution to be an increased reliance on the responsible network operator to instruct connected data centres to switch to back up systems post contingency and coordinate its systems with AEMO to reflect this in pre-dispatch. If this approach is not practically workable, power system operators may be reliant on control schemes to avoid overloading which would have reliability implications for all customers.

  It is important to note the reliability risks for non-data centre customers are greater than data centre customers in the above scenarios. This is because they do not typically have option to disconnect from the grid and transfer to back up power systems.

- Data centres operate with large variable workload profiles, as discussed in Section 3.2. For example, those with fast ramp-up and ramp down, MW-scale pulses without plant level controls to shape grid-side MW variability or ride through disturbances. It would also be increasingly relevant if the proportion of data centres connecting without inverter-based load specific performance standards grows.

Real-time visibility and control of assets connected to the power system underpins our ability to respond to these types of situations.

One known challenge is that transmission operators and operational planners have limited visibility and control of sub-transmission connected assets on a distribution network (e.g. 66kV, 132kV connected plant). For example, it is difficult for the transmission operators to signal large distribution connected data centres to reduce or remove their load in response to a transmission network contingency other than via underfrequency load shedding installed at the data centre facility or at the distribution connection point.

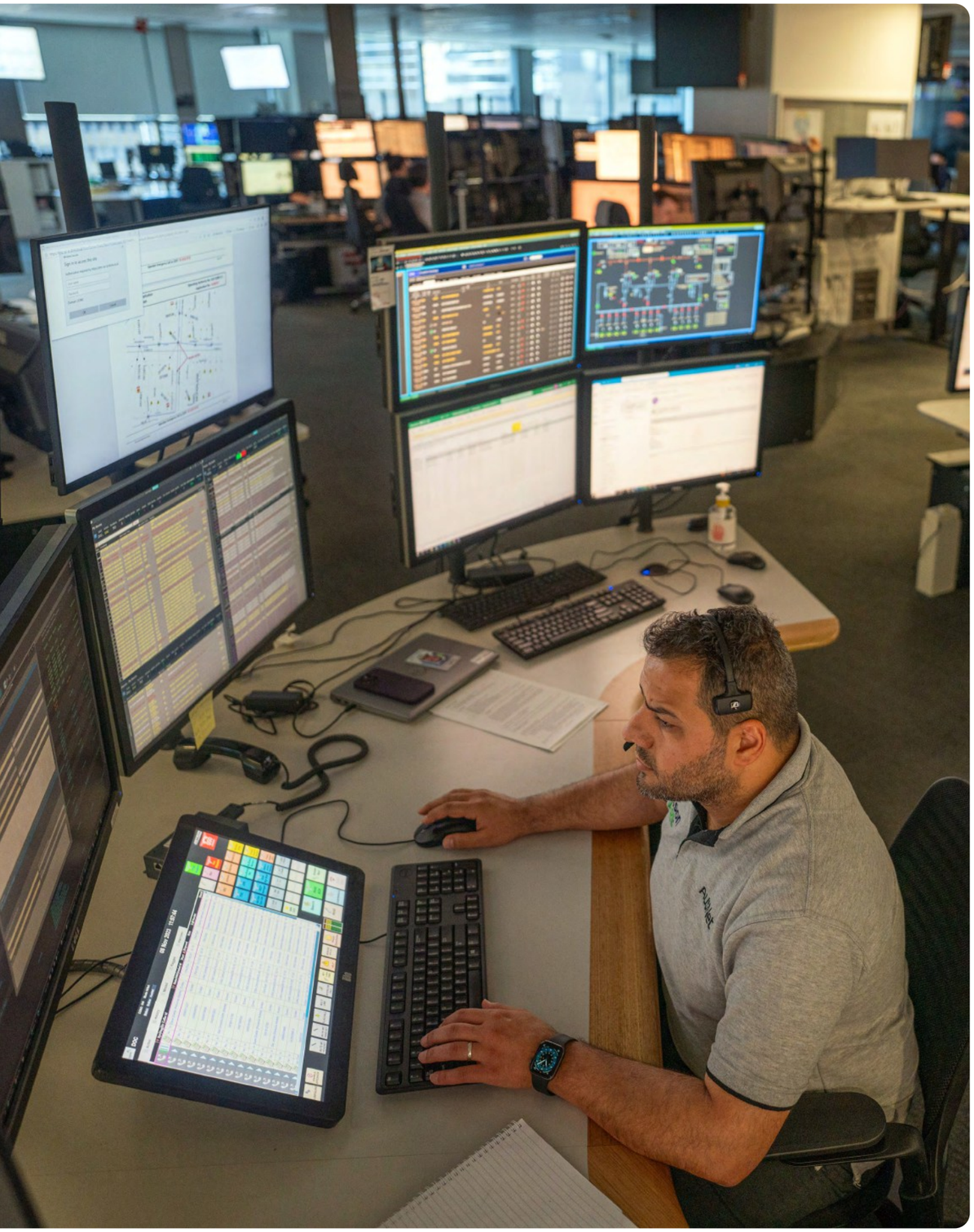
Without real-time visibility and granular controls (i.e. not just switching plant on or off), transmission operators would have a limited set of tools to smooth operational impacts on customers and keep the system secure as the penetration of data centres grows. The box below outlines the types of operational limitations that are currently available to system operators.

Operational limitations relevant to system operators in a high-IBL environment

As IBLs (not subject to performance standards) become a greater proportion of our overall system load and risks grow, system operators including AEMO may have to rely on operational limitations for system stability and security. This may include:

- applying caps on total number of inverters connected in parts of the network to align with technical limits of the power system during system normal and planned outage conditions for pre and post contingency stability
- issuing lack of reserve notices to manage reserve shortfalls, which in some circumstances may require non-priority load to turn off compounding the supply-demand shortfall during an event
- building new constraint equations or updating requirements for generator systems to be online in the distribution system (recognising these solutions are not typically developed for distribution).

It is worth mentioning that real-time visibility and control issues are not new or unique to operating a power system with a high penetration of data centres. NSPs have been grappling with the same challenges with respect to rooftop solar, which is limited by lack of visibility and real time control of low voltage distribution networks. In this case, the aggregate volume of distributed solar has contributed to record low operational demand during the day which tests network operating limits of the transmission system. It is also prone to "shake-off" (disconnection) in response to a transmission network fault, which require careful management of associated credible contingencies.



Potential solutions are understood by operational planners and warrant further investigation:

- **Access to real-time high-speed monitors at data centre connection point(s)**

  On most data centre installations, continuous data recording devices at the point of connection are likely to be required so that over time, the data centre can demonstrate its ability to adhere to agreed technical standards. Given that many such monitoring devices now also provide high-speed real-time data visibility (akin to PMU-like data), this data stream would be extended to the NSP control room for real-time monitoring.

- **Load-shifting or co-generation during periods of energy scarcity**

  During periods of high risk of load shedding in the power system (e.g., LOR 2+), automated signals or manual directions from the NSP control room may be sent to large data centres to request a reduction in energy consumption. In such situations, it may be possible for some data centres to delay execution of low-priority workloads, transfer workloads to other data centres (e.g., in other jurisdictions not subject to load restrictions) or engage their backup supplies to partially or entirely offset the total power being consumed by the installation.

AusNet initiatives improving our ability to observe and control dynamic behaviour

We have an active work program to improve the real-time monitoring and control capabilities via two key initiatives across our transmission and distribution control rooms:

- We are investing $10 million to establish Wide Area Monitoring System (WAMS) capability. This provides high-resolution, real-time visibility of power system behaviour across geographically dispersed assets by using time-synchronised data from Phasor Measurement Units (PMUs). It complements traditional SCADA by capturing fast system dynamics—such as oscillations, voltage instability, and frequency changes—enabling operators to detect emerging risks and act proactively to maintain system security. WAMS supports improved situational awareness, enhanced integration of inverter-based and renewable generation, faster disturbance analysis, and more efficient utilisation of network capacity.
- AusNet's Advanced Distribution Management System (ADMS) is a real-time operational platform used to monitor, control and manage the distribution network and coordinate responses to planned and unplanned outages. ADMS improves fault identification, restoration performance and customer communications by providing integrated, real-time visibility across network operations. It currently delivers operational insight across the high-voltage distribution and sub-transmission network, including HV-connected distributed energy resources, with planned enhancements to extend visibility into the low-voltage network.

Ongoing capability uplifts – such as automated fault restoration, enhanced power-flow analysis, real-time data integration and constraint management for large generators and load – are strengthening AusNet's ability to operate the network safely, efficiently and responsively as system conditions become more dynamic.

Implementation:

Reform required	**Regulatory / Process** Commencing process to investigate practical solutions to improve real time visibility and control of inverter-based loads.
Progress	**Exploratory** AEMO is currently progressing the development of a Market Visibility Framework for price-responsive resources, which is expected to establish requirements for the visibility, forecasting integration and operational use of flexible load behaviour.[91]

91. AEMO, Market Visibility Framework – Summary of approach to policy framework development, May 2026

6.2.3.2. Action 6: Investigate operational planning implications in a system heavily loaded with data centres

Relates to the Chapter 5 Risk Assessment(s):

- 5.2.7 Lack of forecasting and predictability
- 5.3.1 Rapid ramp rates
- 5.3.3 Excessive price responsiveness
- 5.3.5 The risk of frequency instability

Power system operators should explore how operational planning and mechanisms to manage contingency events may need to evolve in a system heavily loaded with data centres. Three areas that warrant further investigation include planned outages, frequency control ancillary services (FCAS) and reactive power support.

Planned outages

From time to time, transmission network service providers (TNSPs) are required to take transmission elements out of service (i.e. de-energise electrical infrastructure) to conduct asset maintenance and facilitate new connection and augmentation works. Planned outages require supportive operational conditions, often over several days in order to go ahead. TNSPs' ability to secure a planned outages is increasingly being impacted by:

1) periods of low system strength
2) system security concerns relating to voltage management, high/low demand and solar shake off[92]
3) an increase in third party planned outages (e.g. other NSPs), making it harder to sequence outage on interstate pathways
4) poor weather conditions.

During an outage, TNSPs and AEMO must plan for the next contingency (i.e. loss of additional network element) and be ready to return the power system to a secure operating state within 30 minutes. This can be difficult with some generation facilities already constrained during the planned outage and limits on the maximum supportable demand (which if exceeded could require load shedding).

In Victoria, these issues have collectively made it difficult for us to plan outages in a window where constraints do not bind. **Figure 25** opposite summarises the complexity of scheduling outages in different parts of the Victorian network and when they are more likely to be undertaken.

We encourage power system operators to consider how a system heavily loaded with data centres could further increase the difficulty to coordinate outage windows. Data centres are expected to increase overall network use and therefore the likelihood that load profiles exceed N-1 threshold in outage conditions. They can also alter minimum demand conditions which are a critical input in outage planning.

In the absence of other solutions (e.g. non-outage techniques, data centre reducing load, network upgrades), we would expect less room in the network to undertake planned outages, further narrowing outage windows. Looking to the future, there may be opportunities for certain data centre workloads to operate more flexibility allowing for planned outage within certain windows.

Targeted network studies of corridors where data centre load is expected to be most prevalent would help clarify the operational planning implications.

FCAS

Stable frequency at or close to 50 Hz is a critical part of maintaining power system security in the NEM. AEMO relies on dispatch processes and FCAS markets to respond to minor deviations in load and generation within a dispatch interval (FCAS regulation services) or correct larger imbalances following a disturbance or rapid ramping (FCAS contingency services).

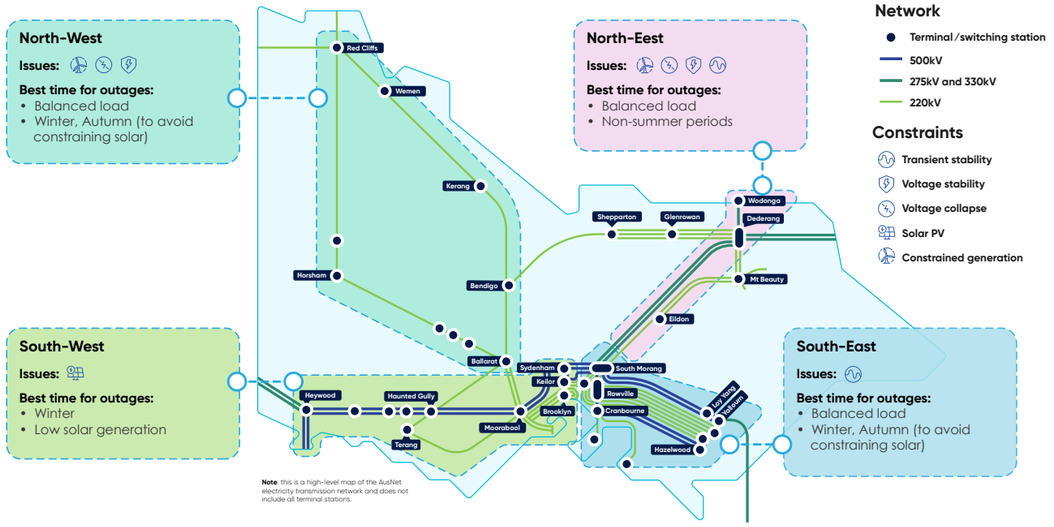
Demand variability and ramp rates can vary for each data centre facility and the aggregate impact of multiple sites are not necessarily coordinated with system stability needs. This large, fast acting-variable behaviour can introduce complexity for system operators in maintaining frequency stability and increase duty on FCAS markets.

We welcome the rapid increase in BESS being commissioned in the NEM with a high degree of frequency capability. However, unless regulation FCAS and/or contingency FCAS volumes are raised in the NEM, we may have inadequate frequency response capability to manage the variability of IBLs when connected at scale. FCAS lower services are particularly relevant to data centres. This recognises they manage scenarios where generation exceeds demand and cause frequency to rise above stable levels.

Some individual data centres projects seeking connection in Victoria over the coming years are expected to exceed the largest existing load contingency, further increasing the risk that FCAS is eroded beyond existing limits.[93]

92. In order to manage system security issues arising from deteriorating network operating conditions AEMO has introduced or modified an increasing number of constraints in Victoria and in other parts of the NEM. These constraints are an "enforcement tool" used to keep the power system within its operational limits. Each constraint equation models a particular limit for a given power system configuration.

93. The volume of contingency FCAS procured within a given region gives consideration to the single largest credible contingency. In Victoria this has remained at 600 MW for many decades, designed to cover the potential loss of the largest industrial load (i.e. Portland Smelter) or the Victoria to Tasmania interconnector (i.e. Basslink).



▲ **Figure 25:** Narrowing outage windows in Victoria

Further investigation is required to consider the feasibility of increasing the maximum allowable size of load contingencies on the network and associated FCAS requirements. For example, whether a change to the market could be allowed that enabled data centres to procure FCAS to cover their impact.

A higher contingent event size may enable network planners to achieve more capacity from the existing shared network (i.e. lift pre-and post-contingency line ratings) to the benefit of connected plant. This needs to be carefully considered in the context of other stability limits and the costs of procuring additional FCAS. A change to the market could be allowed that enabled data centres to procure FCAS to cover their impact.

Reactive power support

Rapid load ramping behaviour of data centres may also have implications for management of reactive power to maintain stable voltage levels on the relevant network. Specifically:

- Whether there will be sufficient quantum of dynamic reactive power support available to reflect load growth driven by data centres and other demand drivers. In Victoria, reactive power support comes from existing synchronous generators, capacitor banks and a small fleet of SVCs. Much of the former is expected to retire reducing reactive power margins. This shortfall will need to be replaced at the same time demand for reactive power support is expected to increase.
- Whether the rate of change in data centre load will increase the need for technologies capable of providing fast acting reactive power support (e.g. SVCs, STATCOMs). Existing VAR technologies such as capacitor banks may not be able to respond and be switched in by network operators quickly enough to stabilise voltage.

Further investigation is required to consider what and when fast acting reactive power support is required in a high IBL environment, giving consideration to the current mix reactive power assets available.

Implementation:

Reform required	**Regulatory / Process** Start process to investigate outage window coordination challenges in a system heavily loaded with data centres Explore feasibility of increasing the existing allowable size of load contingencies on the network and associated FCAS requirements to account for large data centres. Explore need for fast acting reactive power support in a high IBL environment.
Progress	**Not commenced**

6.2.4. Improving our understanding of data centres as they evolve

Purpose: Promote cross industry collaboration on technical elements of data centre integration into the power system, keeping pace with new practices.

6.2.4.1. Action 7: Collaborate on foundational data centre integration issues and keep pace with evolving data centre practices

Relates to the Chapter 5 Risk Assessment(s):

- 5.2.1 Coordination between stakeholders
- 5.2.2 Defining fit-for-purpose technical requirements and standards
- 5.2.6 Insufficient compliance enforcement

As explained in Chapter 3, a single 'standard data centre' does not exist. Data centres not only vary on their behaviour but also continue to refine good practice. We are seeing continuous improvements in how data centres specify, design and operate their electrical, control and cooling systems, orchestrate workloads and load profiles and co-locate (e.g. Data centres and BESS). These characteristics influence how individual and clustered data centre facilities interact with the power system, opening up new opportunities and risks.

We suggest the power system and data centre industries proactively collaborate on technical developments and solutions so to keep pace with evolving data centre design and operational practices. The case for this approach is further outlined in the box below.

The case for collaboration

The current data centre connection landscape bears a striking resemblance to the initial "renewable energy surge" between 2017-2019. Initially, technical issues with how inverter-based resources interacted with the changing grid were emerging, yet there was an absence of clear technical standards, system and market design features to address these concerns. This led to widespread frustration, misalignment and connection delays.

As standards and modelling requirements emerged, they were initially met with resistance. Over time, however, the reasoning for such requirements were better understood by most of the industry and a workable pathway was achieved, enabling project connections to proceed.

A similar trajectory is anticipated in the present context with data centre connections, only this time with the benefit of hindsight from the previous surge. A key lesson was the need to co-design solutions, with representation from both sides from the early design stage onwards to enhance buy-in. While holding out for uniform acceptance from every party would be naïve, leveraging a team comprising power system and proponent perspectives can overcome differing assumptions, capabilities and expectations regarding what is technically required and what is practically achievable.

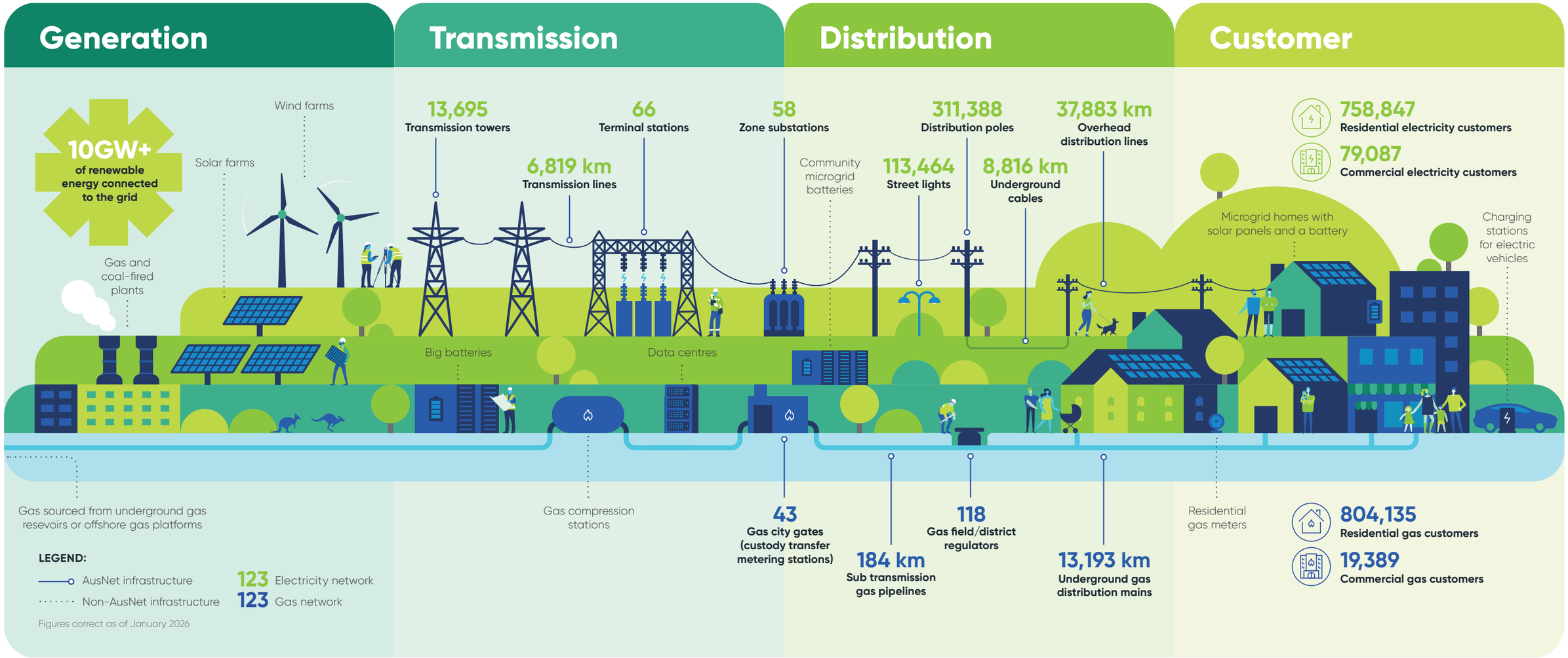
As a starting point, we see value in conducting a technical capability mapping exercise to address to explore foundation integration issues related to data centre grid connection. This could include areas that build on Actions 1 and 2, such as:

- Load ramping capabilities: How quickly and predictably can data centre loads increase or decrease, and what is the prediction for managing variability into the future? (i.e., will it no longer be a problem soon?). Can they be easily categorised (and hence predicted) by data centre type?
- UPS tripping thresholds and behaviour: What flexibility is there with UPS protection settings? What has driven the way they are being set to date? What are the implications to adjust these to better aid with grid support?
- Stability limits: Have UPSs been tested for stability limitations during periods of low system strength, especially when clustered with nearby UPSs from other data centres/manufacturers?
- Grid support capability: Is there any potential scope for UPS equipment to offer voltage control to the power system? Could there be offloading responses to low frequency events?
- Acceptable operating modes: Is there value in standardising operating modes of large-scale UPSs to aid with grid support? (e.g., double-conversion vs. high-efficiency modes). Or is this considered too limiting for customers?
- Data exchange: Can high-fidelity UPS models be provided to power system planners to consider data centre behaviour and treatment in planning studies?
- Stage gates: What information is reasonably required and known at which stage of the project? What can be changed as the project evolves that does not require a reset of studies and analysis?

There are a variety of existing collaborative processes that could be leveraged to give effect to this action. This includes existing data centre connection related technical working groups established by market bodies such as AEMO and AEMC. To the extent possible, these working groups should actively encourage participation and publish insights publicly.

Implementation:

Reform required	**Process** Ongoing and publicly visible data centre and power system collaboration to coordinate insights, share operational experience, or refine technical management of integration issues.
Progress	**Underway** Existing industry working groups are available to give effect to this Action.



About AusNet

We are Victoria's largest diversified energy network business, connecting communities with reliable, affordable and sustainable energy. We own and operate three regulated electricity and gas networks and have a portfolio of contracted energy infrastructure. These networks include:

- an electricity transmission network spanning more than 6,600 kilometres, transporting power to Victoria's five distribution networks, connecting power to NSW, South Australia and Tasmania and supplying power to more than 6.6 million Victorian.
- a distribution network delivering electricity to over 800,000 customers across more than 80,000 square kilometres of eastern and north-eastern Victoria and in Melbourne's north and east
- a distribution network delivering gas to over 820,000 customers across more than 60,000 square kilometres in central and western Victoria.

Our vision is to be trusted to bring the energy today and build a cleaner tomorrow.
For more information visit: **ausnet.com.au**

Bespoke Energy

Bespoke Energy is a specialist power systems engineering consultancy with multi-decade experience in assessing power system needs and enabling the safe connection of inverter-based generation and large loads, including data centres. Drawing on extensive experience with system and network operators, OEMs, and major power system projects and events, our team has led detailed modelling, risk assessment and industry guidance on the interaction of emerging inverter-based technologies with the power system, and on the measures required to maintain stability and security.

We are widely recognised for our thought leadership in power system security, system strength, EMT modelling and grid-forming technologies, and for helping clients adopt new and emerging technologies while meeting stringent regulatory and operational requirements. Through practical, independent advice and close collaboration with industry and market bodies, Bespoke Energy supports innovation while safeguarding power system integrity.

For more information visit: **bespokeenergy.au**

Appendices

A. Glossary of key terms

Active front end (AFE): Type of rectifier system which actively manages the conversion of AC to DC power, allowing for bidirectional power flow.

Active power: The component of electrical power (measured in MW) that performs useful work and is consumed by equipment.

Anchor tenant: A large, committed customer whose demand underwrites infrastructure investment, such as network or renewable generation development.

Australian Energy Market Operator (AEMO): The organisation responsible for managing and overseeing the operation of Australia's gas and electricity markets.

Auto-reclosing: The automatic re-energisation of a power system element after a fault to restore supply if the fault has cleared.

Behind-the-meter generation: Generation located on the customer side of the connection point, supplying on-site load without exporting to the grid.

Composite load model (CMLD): A dynamic representation of aggregated load behaviour used in power system studies.

Connection application: A formal submission by a proponent seeking approval to connect load or generation to the electricity network.

Connection point: The physical and electrical interface between a customer facility and the network.

Contestable transmission services: Transmission assets that may be designed, delivered, and funded by parties other than the incumber transmission network owner.

Contingency: The unexpected loss of a power system element such as a line, generator, or large load.

Credible contingency: A contingency event that the power system is planned to withstand without loss of supply.

Damping: Process of reducing or dissipating the energy of oscillations or vibrations in a system.

Declared shared network (DSN): Victoria's electricity transmission network.

Declared transmission system operator (DTSO): An entity responsible for owning and operating transmission infrastructure in the Victorian declared shared network.

DC/DC converter: A power-electronic device that regulates voltage between different DC levels.

DC link: The direct-current interface with power-electronic equipment linking rectifiers, batteries and inverters.

Digital Fault Recorder (DFR): A device that captures high-resolution electrical measurements during power system events.

Disaster recovery (DR): Backup computing facilities designed to rapidly assume operations following a failure at a primary site.

Distribution Network Service Provide (DNSP): An entity responsible for owning and operating the distribution network.

Double-conversion UPS: A UPS topology that continuously converts AC to CD and back to AC to isolate IT load from grid disturbances.

Edge/micro data centre: A small, decentralised data centre located close to end users to minimise latency.

Electromagnetic transient (EMT) models: A simulation model that captures asymmetrical faults, converter phased-locked loop behaviour and high-frequency resonance.

Energy arbitrage: Buying electricity at low prices and selling at high prices.

Fault ride-through (FRT): Ability of electricity generation source to remain connected and operational during short period of lower electric network voltage.

Fibre connectivity: The use of fibre-optic technology for high-speed data transmission.

Forced oscillations: Sustained power system oscillations driven by a poorly damped control or repetitive load behaviour.

Frequency control ancillary services (FCAS): Market-based services used to maintain system frequency following disturbances.

Frequency disturbance: A deviation of system frequency from its normal operating range due to imbalance between generation and load.

Hall: A physical space within a data centre facility that houses multiple racks of servers and storage systems.

Harmonic resonance: The amplification of harmonic currents or voltages due to network impedance characteristics.

Hosting capacity: The amount of load or generation a network can accommodate without breaching limits.

Hyperscale campus: A very large data centre site comprising multiple buildings with total demand often in the hundreds of megawatts.

Inverter: A power-electronic device that converts DC power into AC power.

Inverter-based load (IBL): A load dominated by power-electronic interfaces rather than directly connected motors.

Inverter-based resources (IBR): Generation or storage connected to the grid through power-electronic inverters.

Islandable: A power infrastructure that can operate independently from the main grid, thereby maintain power during outages or disruptions.

Latency fibre: Time delay when transmitting light signals through fibre optic cables.

Load shedding: The controlled disconnection of load to maintain power system security.

Modular/containerised data centre: Prefabricated data centre units deployed in scalable blocks.

National electricity market (NEM): Australia's interconnected wholesale electricity market.

National electricity rules (NER): The regulatory framework governing operation of the NEM.

Network augmentation: Investment in new or upgraded network assets to increase capacity or capability.

Network constraints: Limits on power flows or connections due to network conditions.

Network service provider (NSP): An organisation responsible for owning or operating electricity network assets.

Network utilisation: The extent to which existing network capacity is used.

Original equipment manufacturer (OEM): A company that designs and manufactures equipment such as UPS systems or inverters.

Over-frequency event: A system condition where frequency rises above normal limits due to excess generation or loss of load.

Phase-locked loops (PLL): Control system that generates an output signal whose phase is fixed relative to the input signal.

Phasor Measurement Unit (PMU): A device providing precise, time-synchronised measurements of voltage and current phasors.

Positive contingency: A contingency where generation exceeds load, causing frequency to rise.

Power purchase agreement: A long-term contract for supply of electricity between a buyer and a generator.

Power quality: The degree to which voltage and current meet defined standards for stability and distortion.

Power shelf: Centralised and scalable power distribution solutions designed for data centres and large server architectures.

Power system security: The capacity of the system to withstand credible contingencies without widespread disruption.

Power system stability: The ability of the system to return to normal operation conditions following disturbances.

Power usage effectiveness (PUE): A metric comparing total facility energy use to IT energy use (calculated by Total Facility Power / IT Power).

Rack: Standardised frame that houses many servers and provides mechanical, electrical and cooling infrastructures.

Rack/rack-level controls: Controls applied at the server rack to manage power draw and ramping behaviour.

Ramp rate: Rate of change of active power over time (MW per second).

Reactive power: The component of electrical power that supports voltage control but performs no direct work.

Recovery ramp rate: The rate at which load connects following a disturbance.

Redundancy: The provision of spare capacity to maintain supply during failures.

Remedial action schemes (RAS): Automated schemes that rapidly alter system conditions following a contingency to prevent adverse outcomes and maintain power system security.

Resonance phenomena: The condition in which a circuit or system naturally oscillates with maximum amplitude at a particular frequency.

Server farm: The collective set of servers forming the core computational load within a data centre.

Short-circuit ratio: A measure of system strength at a connection point.

Static bypass: An alternate AC path allowing load transfer if UPS inverters are overloaded or unavailable.

Static transfer switch: A fast electronic switch transferring supply between independent AC sources.

Sub-synchronous oscillations: Oscillations occurring below the system's nominal frequency.

Successive-fault tolerance: The ability of equipment to withstand repeated disturbances without disconnecting.

System black event: A widespread or total loss of electrical supply.

System strength: The capacity of the network to maintain stable voltage under disturbances.

Transfer logic: Automatic transfer of power from a normal source to an alternate source, used primarily in the event of a failure in the normal source.

Transfer-to-backup: A process where an automatic transfer switch detects power failure and automatically switches the supply from the grid to a backup source.

Transmission network service provider (TNSP): An entity responsible for owning and operating transmission infrastructure.

Under-frequency event: A system condition where frequency falls below normal limits due to excess load or generation loss.

Uninterruptible Power Supply (UPS): Equipment that provides continuous power to critical loads during disturbances.

Uptime tier: An industry classification describing data centre resilience and redundancy.

Variable frequency drive (VFD): A power-electronic device controlling motor speed by varying supply frequency.

VicGrid: Victoria's transmission planning authority.

Voltage disturbance: A deviation of voltage from normal operating limits.

Voltage flicker: Rapid voltage fluctuations that can affect sensitive equipment.

B. Other related work underway

As data centre demand growth in Australia continues to accelerate, government bodies are pursuing programs of work so policy and regulatory frameworks are adequate to support this expansion. This includes:

- AEMC's *Improving the NEM access standards – Package 2* Draft Determination
- AEMO's Large Inverter Based Load interim guidance
- VicGrid's Data Centre Connections in the Victorian Declared Shared Network: Requirements for Application Submission.

Table 14 provides a complete summary of current policy and regulatory framework renewal activities being undertaken by the power sector to enable the growth of the data centre sector in Australia.

Work item	Responsible body	Description of work item
Improving the NEM access standards – Package 2 **Draft Determination**[94]	AEMC	The current NER access standards insufficiently address technical and compliance requirements for large inverter-based loads. The Draft AEMC rule change, published 12 March 2026, aims to mitigate the emerging security and reliability risks associated with the rapid increase in IBL connections for consistent application of the access standards, through the following key proposed changes: • Introduction of a tiered classification structure, based on nameplate ratings, to determine the applicability of Schedule 5.3 access standards for distribution-connected inverter-based loads[95] • Introduction of IBL-specific access standards, including requirements related to disturbance (voltage and frequency) ride-through and instability management • Clarification regarding the application of Schedule 5 protection requirements to primary and back-up power systems • Extension of short-circuit ratio requirements, to apply to large inverter-based loads[96] • Inclusion of mandatory clauses in connection agreements with non-registered participants, such that participants must provide a reasonable degree of assurance that compliance with performance standards is being achieved • Change to the UFLS disconnection regime, to allow faster ramping down, where this is technically feasible • Extension of clause 4.14(n) of the NER, such that it applies to all Schedule 5 participants • Change allowing all Schedule 5 plants to, with reasonable grounds for suspicion of non-compliance with performance standards or the NER, be requested to undergo testing and assessment The draft rule consultation period ended on 7 May 2026.
Large Inverter Based Load interim guidance	AEMO	The Large Inverter Based Load interim guidance is a guideline, to be published by AEMO, will reflect the AEMC's draft determination and provide preliminary guidance to NSPs, developers and OEMs on technical performance model, monitoring requirements to promote a consistent assessment approach across the NEM.
Data Centre Connections in the Victorian Declared Shared Network: **Requirements for Application Submission**	VicGrid	In February 2026, VicGrid implemented the Data Centre Application Submissions Guidelines as a set of 'interim' guidelines to provide specifications around requirements for modelling, studies and performance for data centre connections to the Victorian Declared Shared Network. Note these guidelines do not apply to distribution-connected data centres in Victoria. This document is currently not available publicly, and proponents must contact VicGrid should they wish to obtain a copy.
General Power System Risk Review (GPSRR)[97,98]	AEMO	The 2026 GPSRR Approach Paper, published December 2025, identifies an increase in large load connections as one of four priority risks to secure operation of the NEM. The GPSRR will assess current and future options for management of the risk posed by the rapid increase in IBL connections, as well as exploring consequences of failing to apply proactive mitigation strategies by conducting PSSE and PSCAD studies. The Draft 2026 GPSRR Report was published in May and highlights the potential risks that IBL may pose to the power system if not actions are taken. This includes requirements such as the capability to ride through disturbances, ensuring timely active power recovery, limiting rapid demand ramping, and minimising contribution to power system oscillations It also outlines emerging risks not captured by the AEMC's Package 2 Draft Determination and are actively being considered through sub-working groups, access standard reviews and updates to power system stability, modelling and system strength impact assessment guidelines.
Guide to Registration Exemptions and Production Unit Classifications (REPUC)	AEMO	The Guide to REPUC aims to clarify the process and circumstances around the granting of exemptions from needing to register as a Generator or Integrated Resource Provider under the NER.[99] The upcoming Guide is anticipated to cover exemptions and exemption thresholds for data centre backup generation. This will be released following completion of the associated rule change process, the consultation paper for which is scheduled for publication in June.[100]
Other items in AEMO's work program[101]	AEMO	Updates to the following items will occur, to make provision for Schedule 5.3 loads: • Early Assessment Framework (EAF) guideline • Pre-application support services guideline • Commissioning guideline • Automatic Access Standards The System Strength Impact Assessment Guidelines (SSIAG) will also be updated following the completion of the AEMC's rule change process to incorporate changes in IBL classification. The SSIAG consultation paper is anticipated to be published in June.
ECMC work program[102,103,104]	ECMC	An ECMC-tasked working group, led by DCCEEW, was established in March 2025 to examine the opportunities and challenges associated with forecast national data centre demand growth, and investigate the adequacy of existing regulatory frameworks to facilitate growth in the data centre sector. In December 2025, a final report was delivered to the ECMC, with the following recommendations made, to be progressed by the next ECMC meeting: • Review cost recovery mechanisms, to enable relevant network upgrade and connection costs to be borne by data centre proponents • Increase AEMO's visibility over energy use by data centres • Implement grid connections reforms • Investigate different options for efficient integration of new load, such as implementing demand flexibility, and proportionately increasing firming generation in the system in line with data centre demand growth. Further work is now underway building on the Australian Government's Expectations of data centres and AI infrastructure developers.

▲ **Table 14:** Other related work underway

94. AEMC, Improving the NEM access standards – Package 2 Draft Determination, March 2026
95. Schedule 5.3 is automatically applied to transmission-connected inverter-based loads.
96. Large inverter-based loads are defined in the Commission's draft rule as inverter-based loads with a nameplate capacity 30 MW or greater.
97. AEMO, 2026 GPSRR Approach Paper, December 2025
98. AEMO, Draft 2026 GPSRR Report, May 2026
99. AEMO, Guide to Registration Exemptions and Production Unit Classifications, June 2024
100. AEMC, Improving the NEM access standards – Package 2 Draft Determination, March 2026
101. Ibid.
102. AEMC, Improving the NEM access standards – Package 2 Draft Determination, March 2026
103. ECMC, ECMC Meeting Communique 14 March 2025, March 2025
104. ECMC, ECMC Meeting Communique 8 May 2026, May 2026

C. Additional technical information and descriptions

C.1. UPS Components

C.1.1. Rectifiers

Rectifiers are essential components of data centre UPS systems. They convert the incoming AC utility power into DC, which serves two primary purposes:

- Charging the backup batteries.
- Supplying a DC link for the inverter stage.

In normal operation, a static double-conversion UPS continuously uses a rectifier to convert AC power into DC power. This makes sure the batteries remain charged and downstream equipment is isolated from fluctuations on the grid. Modern UPS rectifiers typically employ voltage-switched semiconducting switching devices, such as insulated gate bipolar transistors (IGBTs), configured as pulse-width-modulated (PWM) voltage source converters. This provides the ability to control reactive power to achieve a near-unity power factor and to draw sinusoidal current from the grid with very low distortion. This active, bi-directional rectifier design can support controlled power back-feed during battery testing, improving maintainability without disrupting the load (where site policy permits).

Modern PWM active-front-end rectifiers synchronise to the supply with a PLL. Therefore, they share some susceptibility mechanisms seen in IBRs; for example, sensitivity to phase-angle jumps, high RoCoF, unbalance, and harmonics[105]

In data centre applications, rectifier capacity ranges from a few hundred kilowatts up to multiple megawatts, depending on the facility size. Large (Tier IV) data centres often deploy UPS modules in the order of one to two MWs each, which can be paralleled to reach a total power transfer capability of three to five MWs or greater.

These rectifier systems are almost universally three-phase in large installations, as three-phase input enables greater efficiency in handling high power and better load-balancing. Single-phase rectifiers (and single-phase UPS units) are only used for smaller loads (typically <20 kVA). They may appear in small server rooms, telecom closets or edge data centres, but are not practical at scale.

In summary, the rectifier stage is a critical front-end in data centre power architecture, enabling AC to DC conversion for battery charging and providing a stable DC supply for downstream inversion.

C.1.2. Inverters

While many industrial loads (like electrolysers or EV chargers) are inherently unidirectional (only requiring rectification from AC to DC), data centres rely on bidirectional power conversion. An inverter stage is necessary to convert DC (from the UPS batteries or DC bus) back into AC to supply the IT equipment during a grid-side power interruption. In a double-conversion UPS (the most prevalent topology for data centres), the inverter operates continuously. Under normal conditions, the inverter takes the rectifier's DC output and produces a well-regulated AC sinusoidal wave for the servers; and during an outage, the inverter draws from the batteries to do the same.

Data centre inverter systems are typically three-phase (outputting three-phase AC power), especially at enterprise and hyperscale facilities for efficiency and capacity reasons. The power ratings mirror those of the rectifiers, ranging from approximately a few hundred kWs up to multi-megawatts when UPS modules are paralleled. Many leading UPS manufacturers (e.g., Eaton, Schneider Electric, Vertiv, etc.) produce these inverter-based solutions in modular form to scale with data centre growth, while achieving efficiencies up to 99%. High-end UPS inverters also incorporate static bypass switches that can transfer the load to utility or generator power if the inverter fails or overloads, adding another layer of resilience[106]

In terms of inverter topology, almost all modern units are Voltage-Source Inverters (VSI) using fast-switching IGBTs or similar. Older or speciality systems might use thyristor-based line-commutated inverters (LCI) or current-source designs, but these are rare in data centres today.

C.1.3. DC/DC converters

Data centres traditionally distribute power as AC, but there is a growing use of DC power distribution and DC/DC converters inside modern facilities. Within high-efficiency UPS architectures, a DC/DC converter between the battery and the DC link provides tighter control of charge/discharge and decouples battery voltage from the inverter bus. This DC converter stage can step the battery voltage up or down as needed to match the inverter's DC link, improving overall UPS efficiency and allowing a wider range of battery types (notably lithium-ion chemistries with different voltage profiles to valve-regulated lead-acid batteries). Some manufacturers label this approach as DC-link regulation or a modular DC/DC battery optimiser in their UPS specifications.

Beyond UPS internals, DC/DC converters are used at the rack-level power distribution in hyperscale data centres. Traditionally, servers each have power supply units converting AC to low DC voltages. But operators adopting Open Compute-style designs have moved to higher-voltage DC distribution within racks (e.g., 48 V DC) to reduce losses. A central rectifier converts facility AC to ~48 V DC, delivered along busbars to each server. Inside the server, DC/DC converters then step the 48 V down to the various lower voltages needed (12 V, 5 V, sub-2 V for CPUs/GPUs). This approach removes one conversion stage compared to traditional AC to 12 V methods, improving efficiency. Google and others have publicly discussed ~30% energy improvements from 48 V rack distribution in certain contexts. Higher-voltage DC distribution has also been proposed (i.e. 380-415 V), with local step-down to 48 V anticipated to become more widely used in the coming years.

C.1.4. Static bypass and transfer equipment

A static bypass (within the UPS) provides a parallel AC path to the load, enabling transfer to utility or generator supply during inverter faults/overloads or under economy operating modes. Separate static transfer switches (STS) may transfer feeders between independent sources (e.g., utility A/utility B or generator A/B). Coordination of transfer thresholds, timing, site protection and upstream reclosing is critical to avoid nuisance transfers during grid faults.

C.1.5. Cooling systems

Cooling systems are critical for maintaining safe operating temperatures of IT equipment. They encompass computer room air conditioners (CRAC), computer room air handling (CRAH), chillers, cooling towers/dry coolers, liquid cooling (i.e., rear-door heat exchangers, direct-to-chip cold plates, immersion), containment, and heat rejection/re-use systems. Major equipment (i.e., fans, pumps, compressors) is predominantly three-phase and increasingly inverter-driven, making the cooling plant an inverter-based load (IBL)-heavy part of the facility with consequential power-quality and stability concerns.

Traditional air-based cooling uses CRACs (with on-board compressors) and CRAHs (with chilled-water coils fed by central chillers). Liquid cooling is growing with high-density racks (30–50 kW+), requiring coolant distribution units (CDUs), leak detection, and carefully controlled loops. Some facilities employ economisers and, where feasible, heat pumps for heat re-use (e.g., district-heating integration). Practical engineering focuses on fan/pump law optimisation, VFD set-points, minimum-flow controls, and containment to reduce compressor hours and improve power usage effectiveness (PUE).

105. See Appendix C.3.2 for further information on RoCoF.
106. See Appendix C.1.4 for further information.

C.1.5.1. Pumps

Pumps are part of the cooling infrastructure, circulating chilled water or other coolant fluids through heat exchangers in the heating, ventilation and air conditioning (HVAC) system. They are typically powered by three-phase AC motors which themselves are electrically driven by VFDs to modulate speed and save energy when full flow is not required. Because VFDs are rectifier-inverter interfaces, pumps behave as power-electronic loads the produce higher power-quality emissions and exhibit increased sensitivity to voltage disturbances. As such, pump VFD control and protection behaviour should be considered in the overall data centre performance assessment.

Pump power is typically a supporting rather than primary load (often representing only a minor proportion of total IT load in highly efficient facilities), but it is continuous and operationally critical. Typical applications include chilled water pumps servicing room air handlers or rear door coolers; condenser water pumps supplying cooling towers or dry coolers; and coolant pumps used in liquid immersion or direct to chip cooling systems to circulate dielectric fluids or coolants between servers and heat exchangers.

C.1.5.2. Compressors

Compressors appear in CRAC units and in central chiller plants. They are substantial three-phase motor loads. Many modern systems use VFD-driven screw or centrifugal compressors for smooth modulation and improved efficiency at lower loads. In smaller rooms, multiple CRAC units may cycle. In large installations, central chiller plants provide chilled water to CRAHs, often with several megawatts of total compressor capacity. From the grid's perspective, compressor starts and large step changes can be material which can be addressed by a soft start.

C.1.6. Alternate energy storage

Some UPS systems use flywheel energy storage instead of batteries for short-term DC supply. These still require an inverter but can recharge and respond extremely quickly. Such flywheel-based UPS solutions are valued for their high cycle life and reduced maintenance.[107] They also save space by eliminating large battery banks. Whether the DC backup source is chemical (batteries) or kinetic (flywheel), the inverter is the critical element that converts DC energy into AC energy needed by standard IT equipment.

C.1.7. Manufacturer examples and real-world applications

C.1.7.1. Power conversion

Eaton, Schneider Electric and Vertiv offer data centre UPS systems with rectifier/inverter capacities ranging from hundreds of kWs to several MWs. Examples include:

- Vertiv Liebert EXL S1: A 625–1200 kVA modular UPS used in large colocation sites which can be paralleled for multi-megawatt installations.
- Schneider Electric Galaxy Family: Employs multi-level IGBT inverters and advertised economy modes up to ~99% in certain operating states.

C.1.7.2. Cooling

Several suppliers manufacture cooling equipment for hyperscale facilities:

- CRAH units: Stulz, Vertiv.
- Water-cooled chillers (frequently with VFD-driven compressors): Johnson Controls (York), Carrier and Daikin.
- Immersion-cooling: GRC, Submer.

Below are some examples of how cooling equipment has been used in practice:

- Microsoft campus in Virginia is described as having a ~34 MW chiller plant with multiple centrifugal chillers (each with ~1 MW compressor motors), illustrating the scale of cooling required for data centre facilities.
- Immersion-cooling vendors deploy pump-driven dielectric-fluid systems in high-density sites (e.g., blockchain and telecom installations).

C.2. Data centre classifications

C.2.1. Important terminology

Table 15 below outlines important data centre energy supply terminology.

Term	Description
Campus	A large, unified site that hosts multiple interconnected data centre buildings or facilities, operated by a single organisation or provider.
N+1, N+2 redundancy	The level of redundancy for a given energy supply component. For example, if there are N+1 UPS, there is one more UPS than what is required to fully supply the load of the data centre.
Power Usage Effectiveness (PUE)	A ratio used to measure the proportion of energy consumed by IT loads (i.e., computers) compared to all the energy consumed by the facility, including cooling and other ancillary loads. An ideal data centre will have a PUE of exactly 1.0 (impractical in reality).
Uptime Tier	The size, sophistication, and redundancy level of a data centre energy supply options. Tier I is a small and basic data centre with little redundancy in supply, while Tier IV is in the hyperscale range with multiple, redundant grid connections and storage and standalone power generation options.

▲ **Table 15:** Important terminology

107. Cycle life refers to the number of charge and discharge cycles a system can endure before significant degradation occurs.

C.2.2. Classification by physical form

The physical form of a data centre strongly influences its scale, siting, and the balance between IT and cooling loads. **Table 16** presents the categorisation framework used in this paper, based on distinct data centre physical forms.

Hyperscale campuses are characterised by very large, relatively steady base loads, overlaid with the potential for rapid variations in power consumption as IT utilisation changes. In contrast, edge and modular or containerised deployments typically manifest as many smaller loads dispersed across distribution feeders. These installations are predominantly non linear in nature, reflecting the widespread use of power electronic equipment.

Non linear loads are those for which the current drawn is not proportional to the applied voltage, resulting in non sinusoidal currents and the generation of harmonics. In modern data centres, most non linear loads arise from power electronic connected devices such as rectifiers and switch mode power supplies, though other technologies, such as arc furnaces in different industrial contexts, may also exhibit non linear characteristics.

Physical form	Typical scale and PUE	Load behaviour	Backup and ride-through	Demand flexibility
Hyperscale campus	• 20 to 100 MW or more per site • PUE ≈ 1.1	• Large, steady base • Rapid power swings possible on top of base load. • Active rectifiers keep power factor near unity and reduce harmonics. • Significant amount of cooling motors.	• Double-conversion UPS + large generator farms (N+1/2N). • Can ride through faults depending on settings. • Can remain disconnected from grid for days.	• Low flexibility for critical services. • Growing use of batteries/job scheduling for ancillary services/ peak shaving.
Edge / Micro	• <1 MW (often 50–500 kW) • PUE ≈1.5–2.0	• Small, traffic-driven bursts. • Non-linear IT loads. • Cooling compressor cycling can be visible in weak systems.	• UPS autonomy can last for minutes • Telecom-grade nodes may have 4–8 h batteries and small generators.	• Moderate per site. • High in aggregate via orchestration (turn down or temporarily move workloads).
Modular / containerised	• Modules 0.1–2 MW; • PUE ≈1.2–1.4	• Predictable, right-sized blocks • Step changes when modules/ halls energise.	• Built-in UPS. • Site-level generators; • Can achieve N+1 redundancy.	• Potentially high where running discretionary compute (shed modules as blocks).

▲ **Table 16:** Classification by physical form

C.2.3. Classification by ownership model

Ownership changes who controls workload scheduling and backup strategy, and therefore the practical demand-response envelope.

Ownership model	Description and scale	Power infrastructure	Grid interaction	Flexibility
Enterprise (on-premises)	• Single- • tenant • Typically 0.1–5 MW	• Varies • Often Tier II–III • Legacy sites may have higher PUE and less sophisticated UPS/cooling sequencing	• Large commercial customer connection • Can comply with power factor and power quality requirements	• Low–moderate • Occasional generator-based peak shaving or batch deferral
Colocation (multi-tenant data centre (MTDC))	• Multi-tenant • 1–50 MW	• Highly redundant (A/B feeds with UPS & generators) • Strict internal power quality monitoring	• Dual utility feeds common • Require coordination for transfers • Strong adherence to power quality limits	• Moderate • Can run on generators/ • HVAC tuning without affecting tenant availability target
Cloud / hyperscaler	• Very large campus clusters (100+ MW)	• State-of-the-art efficiency • Massive UPS/ generators • Sophisticated controls	• Dedicated substations	• High for non-critical workloads (shift in time/place) • Critical services remain non-interruptible

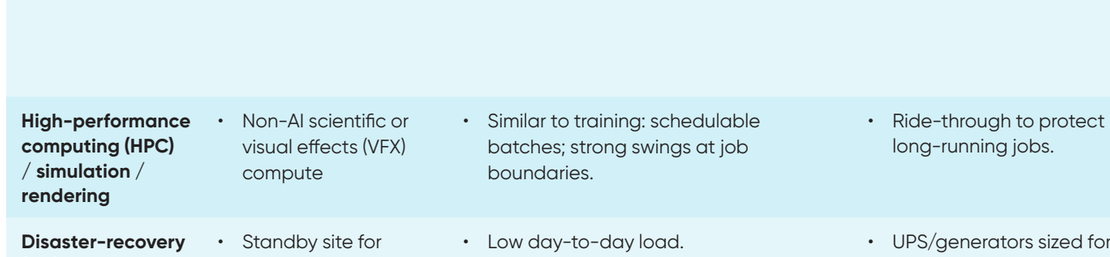
▲ **Table 17:** Classification by ownership model

C.2.4. Classification by functional role (workloads)

Workloads shape the dynamic power signature. For example, AI training involves large, coincident power swings (from seconds to minutes) and benefits from power-capping/frequency-locking.[108] In contrast, inference workloads are more interactive and bursty. Other workload types also exhibit distinct characteristics, as summarised in **Table 18** below.

Functional role	Primary purpose	Load characteristics	Security needs	Grid notes
AI – training	• Batch training of models (GPU-dense)	• Very high utilisation • Phases induce MW-scale swings; high rack densities.	• Robust UPS/generators • Stringent ride-through (loss of compute is costly).	• N/A
AI – inference	• Serving prompts/ tokens in real-time	• Bursty/interactive; lower average than training; suitable for power-capping.	• High availability; air/liquid mix.	• Good candidate for demand response via workload shifting/ capping. • Separate compliance from training clusters.
High-performance computing (HPC) / **simulation** / **rendering**	• Non-AI scientific or visual effects (VFX) compute	• Similar to training: schedulable batches; strong swings at job boundaries.	• Ride-through to protect long-running jobs.	• Coordinate large job starts and ramp rates.
Disaster-recovery (DR)	• Standby site for failover	• Low day-to-day load. • Rapid ramp to full during failover/tests.	• UPS/generators sized for crisis • Often different geography.	• ensure capacity reserved for full-load activation.
Telecom / **network (-48 V DC)**	• Switching centres, central offices, mobile core	• Steady, critical • Large rectifier/battery plants • The ability torun on its own backup power for a long time without the grid.	• Hours of battery + generators • Reinforced, resilient sites.	• Priority loads. • Minimal demand response beyond generator operation. • Typically exhibits a low power quality emissions.
Content Delivery Network (CDN) / **edge cache**	• Localised content delivery	• Small nodes. • Diurnal/event-driven bursts • Partial utilisation typical.	• UPS; often no dedicated gen (hosted in colocation/ telecommunication sites).	• Highly distributed. • Small per-node impact • Aggregate orchestration possible.
Price-sensitive compute	• e.g., crypto mining / flexible jobs	• Ramps with market price; large curtailments feasible.	• Basic UPS. • Generators vary by operator.	• High demand response potential.

▲ **Table 18:** Classification by functional role



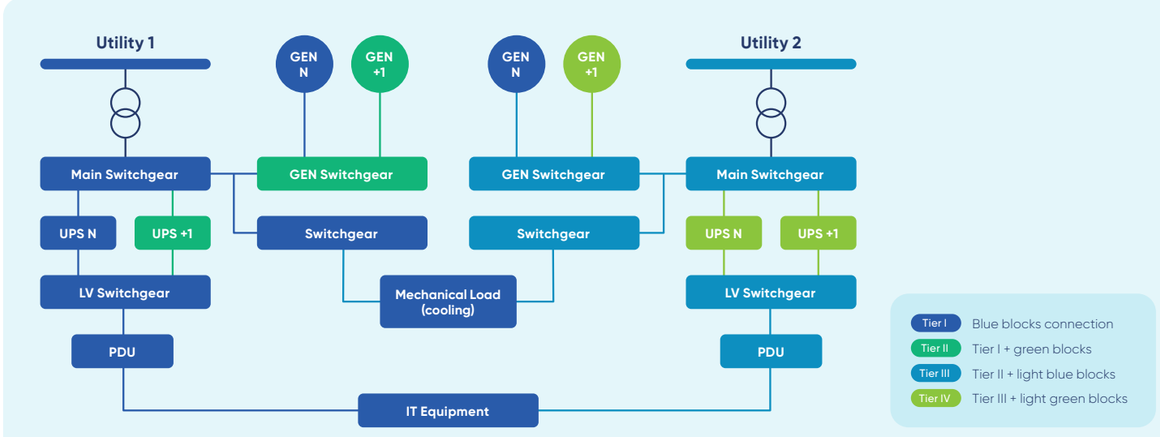
108. Power capping means setting a maximum power use; frequency locking means fixing device clock speeds so power does not surge.

C.2.5. Classification by Uptime Tier (redundancy)

Uptime Institute Tiers I–IV determine redundancy and acceptable downtime. Tier I/II sites often island on a single generator path and may drop load for maintenance. Tier III supports concurrent maintainability, and automatic transfers can shift the full IT load between paths or onto generators with no outage. Tier IV is fault-tolerant 2N where any single failure causes no IT impact. **Table 19** breaks down this classification, with **Figure 26** graphically describing these components.

Tier	Primary purpose	Load characteristics	Security needs	Grid notes
I	• Single path • No redundant components	• UPS and generators present but no redundancy • Downtime on any component failure/ maintenance	• One utility feed • Likely to drop to generators or offline in disturbances	• Small loads • Treat as standard commercial customers • Low demand response maturity
II	• Single path • N+1 (one spare) components	• Ride-through with one spare • Still outage for path maintenance	• One feed (alternative line possible) • Generator-based operation more reliable than Tier I	• Medium sites • Possible generator-based peak shaving
III	• Concurrent maintainability (dual A/B paths; N+1)	• No IT downtime for maintenance • Seamless transfer to another path • Generators cover utility loss	• Often dual utility • Automatic transfers/ shifts between lines	• Coordinate transfers • Good power quality compliance • Viable demand response via generators/cooling (HVAC) without IT impact
IV	• Fault-tolerant 2N (two independent full-capacity paths)	• Any single failure causes no IT impact • Continuous cooling • Instant source transfer	• Dual active utility sources • One source can pick up full load instantly	• Protect against unintended reverse power • Minimal curtailment appetite • Priority restoration

▲ **Table 19:** Classification by Uptime Tier



▲ **Figure 26:** Classification by Uptime Tier

C.3. Disturbance descriptions

The following sub-sections outline a range of plausible disturbances that may affect the Australian power system, including both natural and operational disruptions.

C.3.1. Faults and voltage disturbances

C.3.1.1. Fault-based voltage disturbances

Power system faults can occur at any time in the NEM and for a variety of reasons. These are generally outside of the control of the asset owner and power system operator, and their impact can range from an immaterial temporary interruption to far-reaching and extremely complex consequences.

In a best-case scenario, a "normal", single fault on a power system component usually results in:

- A rapid, temporary reduction in voltage on one or more phases.
- A disconnection of the faulty power system component, such as a transmission line, transformer, or distribution feeder.[109]

Depending on the component, an attempted re-connection of the faulted component can result in:

- A return to normal conditions and reconnection of the affected component if the fault has naturally cleared itself; or
- A second rapid, temporary reduction in voltage in one or more phases if the fault still exists, which will result in the component being permanently removed from service until it is inspected and the protection mechanism is reset.

Within the NEM and in Victoria, possible faults include:

- Short-circuit between conductors and/or ground due to a foreign object.
- Tower or pole collapse resulting in conductors contacting each other or ground.
- Short-circuit between conductors and/or ground due to reduced circuit insulation capability (which may arise from bushfire smoke for air-strung conductors and breakdown of insulator to ground for cables).
- Lightning strikes, resulting in energy surges that exceed the rating of insulators (known as flashover), causing a short circuit.
- Loss of phase due to conductor disconnection (without connection to another phase or ground).

Most faults are dealt with by protection systems that remove the damaged portion of the system very quickly and within set standards / tolerances. However, occasionally faults can occur that are so severe that they were not reasonably predicted as likely (known as a non-credible contingency) or cause cascading events / consequences which were not predictable from the information known prior to the event.

C.3.1.2. Other voltage disturbances

As with network faults, other voltage disturbances may appear at the data centre point of connection as unacceptable high or low voltage levels, potentially triggering disconnection from the power system. While such disturbances are generally less frequent, they must still be considered in a holistic assessment of system behaviour and the ways in which data centres may respond. Examples of voltage disturbances include:

- Sustained, wide-area reduction in voltage due to large generator control or protection error.
- Sustained, spontaneous voltage oscillations throughout large geographical regions.
- This could be from incorrectly functioning generator sources (e.g., the West Murray oscillations[110]), or from load sources, drawing large, coincident amounts of power from the system at regular intervals (as may be the case for clusters of data centres).
- Failure or misoperation of reactive support plant such as Static VAR Compensators or shunt capacitors.
- Misoperation or excessive and unexpected customer load draw, resulting in more energy being drawn than the circuit and its voltage regulation mechanisms were designed to handle.
- Failure or misoperation of voltage-regulating transformers.

109. This can have other implications such as a reduction in power transfer capability of the network.
110. AEMO, West Murray Zone Intermittent Power System Oscillations, September 2021.

C.3.2. Frequency disturbances

Frequency is a second-order effect, indicative of a supply versus demand imbalance in the power system. Underfrequency events (more common today) occur when there is suddenly insufficient generation to meet demand. Overfrequency events (less common today) occur when there is suddenly too much generation compared to demand. Frequency disturbances in the NEM can be caused by:

- The sudden disconnection of one or more major generators, with or without sufficient inertia in the remaining system.
- The sudden disconnection of one or more major loads, with or without sufficient inertia in the remaining system.
- The sudden disconnection of one or more interconnectors between NEM regions under heavy flow (importing or exporting).
- A fault or major voltage disturbance experienced by large numbers of heavily exporting rooftop photovoltaic (PV) inverters (e.g. residential PV systems), causing widespread disconnection from the grid, followed by uncontrolled reconnection at full export once normal conditions are restored.
- A fault or major voltage disturbance that is seen by large loads (such as data centres) resulting in their disconnection from the grid.

Large frequency events (both high and low) that exceed the headroom capacity of generators to increase or decrease their power output are serious matters that are generally handled through the bulk disconnection of power system elements.

For low-frequency events, load (such as residential, commercial and industrial customers) is rapidly disconnected from the power system to attempt to restore the system to normal operational bounds. For high-frequency events, generators are rapidly disconnected from the power system to bring the system back within normal bounds.

While generators are the primary responders to such events, there is scope for loads to play a role in maintaining power system frequency, where technically capable.

A further aspect of a frequency event is how quickly it materialises, known as the RoCoF. In the NEM, RoCoF up to ±4 hertz per second is contemplated. Although this is considered to be high by world standards, it is a feature of the sparsely interconnected and "light" power system.

C.3.3. Oscillations and resonances

Power system oscillations and resonances are non-ideal scenarios where one or more components of the power system interact with one other in an uncontrolled manner, causing oscillatory energy transfer between components. Left unbound, this can cause protection systems to operate, interrupting customer supply and potentially wide-area blackouts. Examples of oscillations and resonances include:

- Torsional oscillations between large synchronous machines centres (e.g., Latrobe Valley) and the remainder of the NEM.
- Controller interactions of multiple power electronic interfaced equipment including both IBRs and IBL.
- Forced oscillations due to a large generator or load misoperating or drawing a regular, pulsing amount of power from the system (e.g., drag-lines).

The presence and likelihood of oscillations may be identified during planning studies, where models of sufficient fidelity for all prominent components of the power system are used to evaluate the performance of the power system for most credible scenarios. Solutions to these oscillations can then be designed and deployed by changing of plant characteristics or connections, power consumption ramping profiles, or control system settings without exposing the power system to risk.

C.3.4. Low system strength

Periods of low system strength refer to a reduced ability to maintain stable voltage and support the operation of connected equipment, especially during disturbances. Generally, system strength is higher when there are more synchronous machines and grid-forming generation sources online (more 'leaders'), and lower when grid-following generators and loads dominate the energy mix (more 'followers'), based on the availability and price of grid resources throughout the day. There are many subtleties and aspects of system strength (voltage waveform stiffness, equivalent apparent grid impedance, short circuit amounts, etc.). But in the context of data centres, periods of low system strength increase the likelihood of grid-connected control systems of both generators and inverter-based loads becoming unstable or interacting with other nearby plant. This is predominantly due to the reduced stiffness in the voltage waveform of the local power system.

Many initiatives are currently underway throughout the NEM and Victoria to make sure sufficient system strength is maintained such that grid-following controllers and protection mechanisms correctly operate 24/7. However, given that inverter-based loads (including data centres, variable speed drives, etc.) can also be susceptible to low system strength periods, it is critically important that grid operators and network owners are aware of the stability limits of inverter-based loads, and have confidence that these loads have also been reasonably tuned to withstand periods of low system strength commensurate with the location in which they are connecting. If this is not the case, it is possible either that:

- The grid operator may under-procure the amount of system strength services required to maintain the stability of large inverter-based loads.
- The inverter-based loads themselves may become unstable with or without the presence of a grid-side disturbance, causing forced oscillations on the power system and/or causing one or more large inverter-based loads to trip offline in a given geographical area due to the presence of such instabilities.

C.3.5. Low probability disturbances

Major power system disturbances which can, but are less likely to, occur include system black events, and geomagnetic storms. While procedures and protocols must be in place to protect against these events, they are seldom triggered.

- System Black events result in the loss of supply for a major geographical area or entire state. Notable events include:
- 2016 South Australian blackout – Result of storm damage and unexpected behaviour of generation sources.
- 2009 Northern Queensland blackout – Result of cyclone damage to transmission infrastructure.
- 1964 New South Wales – Result of major loss of supply
- Geomagnetic storm events can result in catastrophic damage to network equipment, causing cessation of supply to large areas of the power system. No events have been directly attributed to such geomagnetic storms in Australia to date.

C.4. Victoria network service provider roles and responsibilities

In other NEM jurisdictions, AEMO performs the role of national transmission planner, but the local primary TNSPs and DNSPs have overall responsibility for operation and maintenance of their respective networks, including network planning, procurement and delivery, connections management, pricing, operations and maintenance.

Unique features of Victoria's transmission framework

In Victoria, TNSP functions are split between VicGrid and the owners of the transmission network, called declared transmission system operators (DTSOs).

Under declared shared network (DSN) arrangements, VicGrid, acting as a Victorian TNSP, is responsible for network planning, procurement, connections management, pricing and the provision of shared network services to network users.

AusNet is the principal DTSO, owning and operating the vast majority of Victorian shared transmission network assets. DTSOs operate, maintain and replace the transmission network, and have agreements with VicGrid to provide electricity network services to support its functions.[111] This includes providing non-contestable transmission services (e.g., interface works to connect new network infrastructure to its existing transmission network).

The provision of connection assets typically involves a negotiated and contestable transmission service. For example, a developer for a data centre project submitting a connection application to VicGrid can nominate a DTSO to build, own, operate and maintain the physical connection asset and associated shared assets.

Organisation	Key role	Responsibility
VicGrid	Newly established entity overseeing the planning of the Victorian declared shared network.	Plans the DSN including the preparation of the Victorian Transmission Plan and Victorian Annual Planning Report. Determines whether augmentations are contestable, and conducts tender processes with DTSOs, unless selected prior by developer. Provides transmission network services, procured through its agreements with DTSOs. Manages connection applications to the DSN including performance requirements and approval. Oversees transmission pricing.
AusNet (principal DTSO)	Owner of the majority of the Victorian Transmission network and planner for asset replacement.	Builds, owns, operates and replaces DSN transmission assets, including high-voltage lines and terminal stations. Builds, owns and operates physical transmission connections. Provides non-contestable transmission services.
PowerCor, Jemena, CitiPower, United Energy, AusNet Services (DNSP)	For the Victorian state, owners of the distribution and sub-transmission networks (≤ 66 kV).	Plan, owns, operates and maintains its distribution network with geographically defined area. Manages connection applications to its distribution network.

▲ **Table 20:** Victorian network service providers

111. Other DTSOs include Transmission Operations Australia, Lumea, Murraylink and Rowville Transformer Limited.

D. Approach to prioritising risk factors

How to read Table 8

Table 8 provides a screening prioritisation of risk factors to support sequencing of effort and to keep the focus on the highest-necessity issues first. Scores are not intended as quantified probabilities.

Relevance scope (NEM vs Victoria)

Relevance is assessed for (i) the NEM overall, reflecting potential system-wide impacts and issues that can propagate beyond a local node/area, and (ii) the Victorian context, reflecting the plausibility and potential severity given likely connection locations, corridor concentration, and network characteristics. The Victorian score reflects exposure and near-term plausibility, not different underlying physics. For most process-related risks including coordination, fit-for-purpose requirements, modelling scope, and compliance assurance, relevance is treated as broadly consistent across the NEM and Victoria because the underlying drivers are governance, information, and assurance pathways rather than jurisdiction-specific network conditions. It is recognised that several AEMO and broader industry initiatives are underway to improve data centre characterisation, visibility, and coordination, and the intent of the observations and priorities in this chapter is to reinforce and help focus those efforts rather than diminish their value. Many initiatives are still in progress and have not yet concluded or been implemented consistently across NSP processes, so this assessment highlights where clearer standardisation and assurance pathways are still needed.

For technical risks, the key delineation is whether the dominant mechanism is primarily local (driven by corridor impedance and configuration and including resonances that depend on frequency-dependent network impedance) or system-wide (driven by coherent MW steps, ramps, or recovery trajectories that materially influence frequency control, reserves, and broader system security). Where a risk is predominantly local, a larger interconnected system may provide greater resilience in aggregate, but local impacts can still be severe in weak-grid areas. Where a risk is system-wide, or can become system-wide through coherent behaviour, increasing the number and clustering of connections can accumulate the risk and increase the effective contingency size, even if each individual site impact appears local.

This is particularly relevant for fault ride-through and recovery behaviour. Although disturbance response is initiated locally at the connection point, coherent transfer-to-backup and recovery across multiple halls or multiple sites can translate a local fault sequence into a material aggregate MW change with broader system security consequences. Accordingly, any differences between Victoria and the wider NEM are reflected explicitly in the per-item 'Relevance to the NEM' and 'Relevance to VIC' scores.

How scores were determined

Scores were assigned by combining three lenses. These were evidence from Chapter 3, assessment framing and disturbance conditions from Chapter 4, and Chapter 5 consequence and urgency for connection outcomes and system security. Timeline scores reflect a judgement on when each risk becomes a practical driver for requirements, study conclusions, or mitigations, recognising that some risks are already material today while others scale with the number, size, and electrical proximity of new connections.

How to read Table 9

In practical terms, **Table 9** is a scoping aid. For example, rapid ramp rates and price-responsive behaviour primarily manifest as frequency-control burden and, in some cases, local voltage issues, while disturbance behaviour (ride-through, transfer-to-backup, and recovery) can lead to larger system consequences including emergency scheme activation if the aggregate MW change is large.

Cumulative impact is treated as the effect of coincident or coherent response across multiple geographically close sites experiencing the same initiating event (for example faults, auto-reclosing sequences, or broader disturbances). In this case, what is electrically a single network event can translate into a larger aggregate outcome because multiple data centres respond similarly rather than independently, and corridor concentration can further amplify the system-level effect.

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