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Australian Research in Power System Transformation

Topic 6 – Essential System Services

2025/26 Characterisation of Loads for Essential Services

Commonwealth Scientific and Industrial Research Organisation

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Contents

1. Introduction

1.1 Background

The Australian power network is currently undergoing one of its most significant engineering transformations since the Industrial Revolution. Historically, electricity was generated at a small number of large power stations and delivered to consumers via long-distance transmission systems. Now, the current trajectory is towards a decentralised power system that generates energy from numerous distributed energy resources (DER) such as community batteries, utility-scale solar, home rooftop solar, batteries, and electric vehicles, located throughout the network. This transformation is being driven by the national transition to net-zero emissions and the ongoing need for secure, reliable energy. By 2050, almost half of Australia's electricity supply is expected to come from millions of privately owned distributed generators. A coordinated and well-planned approach is therefore essential to ensure energy security as these new sources are integrated into the system (Hargroves et al., 2023; Race for 2030, 2023).

Planning for this transition requires an understanding of how electricity use will evolve. Changes in what energy is used for, and when it is used, must be considered to ensure supply remains available when required. Traditional grids lacked tools to manage this variability, but demand-side management (DSM) now plays a critical role in forecasting and balancing short-term future energy needs. DSM helps maintain system stability by better aligning demand with supply, relieving local network stress, and supporting performance, reliability, frequency and voltage stability, and overall power quality. Beyond system security, DSM can also respond to consumer-driven signals—for example, reducing load during high-price periods or increasing consumption to absorb excess renewable generation (AEMO, 2025; ARENA, 2025; CSIRO and Energy Networks Australia, 2017; Race for 2030, 2023; IEA, 2022).

Looking ahead, residential Consumer Energy Resources (CER), a subset of DER, are expected to become increasingly controllable. At the same time, electrification will significantly increase electricity demand over the next 25 years, particularly within the industrial and commercial sectors. Although improved energy efficiency and distributed generation such as rooftop solar will offset some of this growth, industrial and commercial loads are still projected to account for most of the electricity supplied through the National Electricity Market (NEM). Understanding the nature and controllability of these industrial loads is therefore a vital step in delivering a least-cost energy transition (ARENA, 2025; AEMO, 2024; AEMO, 2020; Consumer Energy Resources sub-Working Group, 2025; William et al., 2023).

1.2 Purpose and Outcomes

The purpose of this research project is to investigate and determine the potential for industrial generators and loads in the Hunter Region, Australia, to participate in demand response and provide system services; the barriers to that potential; and the implementation path to realise it. The research will be carried out through direct engagement with industrial energy users and is intended to provide crucial information for power system planners, regulators and researchers. Furthermore, the project will consider which commercial incentives are necessary to ensure that plant owners participate in the provision of system services.

The proposed project builds on the current work conducted under AR-PST Topics 4, 6, and 8, shifting the focus from long-term possibilities (10-15 years) to outcomes that are likely to be achievable over the next foreseeable future (1-10 years).

The outcome of the project will be a clear understanding of how medium-scale industrial loads can act as system services and the quantification of the services potentially available from these loads. This information will be required for future power systems to maintain a reliable supply-demand balance at least cost with higher penetration of renewables. The project will also develop a taxonomy of industrial load and generator types to detail the overall potential capacity of industrial-based system services provision within the National Energy Market (NEM). In addition, it will provide a clear understanding of the barriers to commercial projects acting as a major source of system services, and what changes or incentives would be needed to overcome these barriers. The outcomes of the project are intended to support both the research community and practitioners involved in real-world power system planning and operations.

2. Research Completed

2.1 Literature Review

2.1.1 Demand Side Management (DSM)

To date, most load management and demand response (DR) programs have been designed and implemented for residential loads. Industrial energy users are not considered viable options for load management applications; this is mainly due to the greater complexity of their energy demand and the equipment used, compared to the residential sector, as well as the limited understanding of the true industrial potential of DR (Bjork & Karlsson, 1985) (Shoreh, et al., 2016). However, given that industrial plants are among the largest energy consumers and that, in the future, the largest growth in energy demand will predominantly come from the industrial sector, it is surprising that there is relatively little literature on this subject (AEMO, 2024). The primary objective of load management remains system balancing, ensuring that supply matches demand, relieving network stress, supporting system reliability, frequency, and voltage stability, and improving power quality.

Much of the existing literature focuses on the potential of residential demand-side participation, with limited attention extending to industrial settings. Where industrial DSM is considered, research has largely concentrated on the low-hanging fruit of accessible loads, such as HAVC systems, lighting, space heating and cooling, water heating, pool pumps and irrigation systems (Gellings, 2017). However, some more recent studies move beyond this and highlight the potential for industrial consumers to provide flexibility to the power system through DR programs (Zhang, et al., 2025).

Types of industrial sectors that have been identified as primary energy consumers, and have the potential for demand side participation, include metal production, oil refineries, chemical and cement production, food processing and printing industries. Further breakdown of the main sectors and process types has identified those with the potential to provide system services and participate in demand response, including mechanical processes that use electric motors with storage or inventory buffers, such as milling and grinding; variable speed drives (VSDs); heating and cooling processes with thermal storage, such as electric furnaces, electric heating, and refrigeration; and metal refining with electrolysis (William , et al., 2023) (Scharnhost, et al., 2024).

Despite the relatively limited focus of the existing literature and the challenges associated with implementing DSM in industrial settings, there is strong evidence that industrial loads have significant potential to participate in demand-side management, particularly demand response. Harnessing this potential is expected to play a critical role in balancing electricity systems with increasing penetrations of renewable energy.

2.2 Stakeholder Engagement

Advitech focused its stakeholder engagement to a single region, the Hunter Region NSW, to ensure effective data collection and meaningful face-to-face engagement, as well as being able to focus on certain load characteristics (PFC and DOL motors), time of use, and functions of our stakeholder participants. The Hunter is also Australia's largest regional economy with a diverse industrial base and growing renewable energy sector. Advitech's 30-year presence in the Hunter also provided an established network to support this research.

Advitech's engagement strategy centred on industrial energy users across a range of business sectors. Utilising its industry connections, Advitech identified stakeholders with flexible processes or significant energy consumption or generation profiles. Initial outreach to approximately 50 industry representatives resulted in a

40% response rate, followed by a subsequent 28% participation rate. Initial meetings with participants involved a standard set of questions, with insights from those discussions informing more detailed, tailored assessments aligned with the objectives of this research.

Current stakeholder participants come from 5 industry sectors, including Agricultural, Construction, Manufacturing, Mining, Technology, and Media and Telecommunications. Breaking the sectors down further there are representatives from the following business types:

- Data Centres;
- Coal Mining;
- Meat Processing;
- Rail and Transit Systems;
- Heavy machinery equipment overhaul servicing;
- Manufacturers of cladding, steel, human therapeutics, fluid asset intelligence solutions, wheels, drilling equipment, and tool systems;
- Machining, repairs and fabrication services for mining, defence, transport and food industries; and
- High-voltage electrical systems, safety solutions, and communication infrastructure for mining, tunnelling, and heavy industry.

3. Outstanding Activities

The first half of this project was fundamental in establishing our focus area, engaging participants across a range of industry sectors, and collecting data of industrial loads capable of providing system services. The next half of this project will focus on building a deeper understanding of our participants industrial load capabilities whilst in parallel continuing stakeholder engagement activities to ensure we have a diverse range of industry sectors participants. A taxonomy of industrial loads will be developed based on our participants operational characteristics, power requirements and functions, followed by a detailed analysis of data collected around available load types as well as the barriers to successful participation in the provision of power system services.

4. Progress against the Roadmap

The AR_PST roadmap includes significant focus on demand-side participation and distributed energy resources. To the knowledge of the authors, this primary research reflects the first recorded engagement with diverse industrial loads regarding their ability to unlock additional demand flexibility. It is expected that the data that is collated as the result of this project will form an important basis for any future work regarding incentive schemes for load shifting. In the updated research scope, the research also collated additional information about the presence of frequency and voltage regulating assets (specifically, direct online motors and Power Factor correction, respectively). Concretely, the research meaningfully progresses open question 1.3 from Roadmap Topic 6 research plan (RMIT University, 2021).

5. Research relevance to Australia

As Australia progresses toward net zero by 2050, the retirement of coal-fired power stations and the increasing penetration of intermittent renewable energy resources are reshaping the electricity system. This transition has increased Australia’s energy market volatility and requires a rethink of traditional grid management strategies to maintain system stability, reliability and efficiency in an increasingly decentralised system. In the

Australian electricity market, the Australian Energy Market Operator (AEMO) is responsible for coordinating dispatch to ensure real-time balance between supply and demand. This process is inherently demand-driven. However, increasing variability in generation can lead to frequency and voltage instability if not properly managed (Nami, 2024).

Demand-side management, enabled by smart grid technologies, provides a means to address this challenge by shifting electricity consumption to periods of high renewable output. Through tools such as dynamic pricing, load control, and schedulable loads, demand response can support system balance while also reducing curtailment.

Australia currently has an unquantifiable number of existing loads operating at the megawatt level. Given the magnitude and operational flexibility across sectors, industrial load will not only be critical to the future provision of system services but must also be considered in any planning activities involving the use of distributed energy resources. In a decentralised yet highly interconnected energy system, electricity networks must be responsive to shifting demand patterns while also enabling coordination across a diverse mix of energy resources. When considered together, the key engineering challenge is the development of a "digital nervous system" that integrates real-time renewable forecasting with automated demand-side management, enabling efficient coordination of supply and demand across both industrial and residential sectors (Zhang, et al., 2025) (Race for 2030, 2023) (William , et al., 2023).

6. Recommended Research Priorities

Based on the work completed in the first half of this program, Advitech recommends the following:

6.1 Adoption of an Industrial Demand Response Standard

As discussed earlier in this report, AS 4755 Demand Response Standard encompasses the capabilities and modes that enable residential appliances and smart devices to participate in demand response (AEMO, 2020). This standard allows residential loads to shift or modify energy consumption in ways that support demand-supply balance and enhance power system security. Against this backdrop, once industrial loads capable of participating in demand response and provide system have been identified, the next step is to determine the challenges associated with developing an equivalent demand response standard for the industrial sector. Key questions include: what barriers arise to implementing demand-response capability at an industrial scale, and how can these be addressed to successfully establish such a standard?

The establishment of an industrial demand response would support the development of regulatory frameworks and incentive schemes that may prevent large energy users from selecting to operate off-grid. While this idea may appear counterintuitive, the increasing cost-effectiveness of energy storage systems could incentivise self-sufficiency among large energy consumers. Widespread migration of industrial loads off-grid would reduce system flexibility, potentially leading to increased grid instability and negative consequences for power system operation. Industrial loads provide valuable support in absorbing surplus generation; if these loads are offline or removed from the grid, curtailment would increase with low-demand events becoming more severe. The migration of large energy users off-grid could have serious implications on the reliability of the grid, such as driving frequency imbalance, loss of major sources of demand response, an increase in infrastructure costs being passed to consumers and thereby, increased electricity prices. In addition, large thermal generators are required to operate above their minimum safe operating level; during periods of very low demand, reduced system load will force generators to work below safe operational demand, increasing the risk of unit failure and thus an increased risk of blackouts (Pearson, 2021) (AEMO, 2024) (AECOM, 2014).

Australia has a substantial number of loads that could, in principle, be controlled as DER; however, a range of technical, economic, regulatory, social, and operational barriers must be overcome before this can be realised. Addressing these challenges will be essential to the development of a robust and practical demand response standard applicable to industrial loads.

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