Accelerating Energy Transition Series

ENGINEERS AUSTRALIA

The revolution will be in distribution: Faster, cheaper decarbonisation through integrating Distributed Energy Resources (DER)

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Summary

While Australia has more rooftop solar per capita than any other nation, engineering and regulation lags mean the potential for Distributed Energy Resources (DER) to expedite the energy transition remains yet to be fulfilled. This essay outlines how DER integration could create a minimum of $19 billion in energy system net benefits by 2040 and what needs to happen to achieve these.

Power system engineers need to work jointly with regulators and policymakers to ensure improved visibility, communications and data flows in distribution networks; that distribution network voltages are within regulated limits; that dynamic operating envelopes (also known as flexible exports) are rolled out across the National Electricity Market (NEM) and Western Australian Wholesale Energy Market (WEM); and that DER are able to provide distribution network support services and other energy system services. Engineers have a vital role both in making the changes to the operation of the distribution network to support DER integration and inform policymakers to ensure Australia can meet its target of 82% renewable electricity supply by 2030. Without engineers thinking holistically and innovatively about DER integration, the energy transition will be slower, more costly and less resistant to future shocks.

Distributed Energy Resources (DER) have the potential to create faster, cheaper, more resilient decarbonisation

Distributed energy resources (DER) are small-to-medium-scale energy resources connected to the distribution network, either in front of or behind the meter.

There are three broad categories of DER:

1. Distributed generation: electricity generated at or close to the site of use.
2. Energy storage: capturing energy locally produced at one time in chemical, thermal or other forms for use at a later time.
3. Flexible demand: appliances or machines which are able to have their time of use altered passively (e.g. through a timer) or dynamically in response to local or external signals.

A DER taxonomy is provided in the Appendix.

Greater uptake and better integration of DER have the potential to speed up and help lower the overall cost of Australia's transition to 82% renewables by 2030. This is because:

- consumers pay more of the capital cost of the generation and storage directly
- DER is co-located with load, reducing network and retail costs
- the smart on-site use of DER reduces the use of the network and reduces network peaks
- there is large capacity available in Australian distribution networks most of the time
- the time efficiencies compared with large-scale generation and transmission construction are significant, and
- the social licence issues are minimal.

Far from being 'at least 20% of our energy solution',[1] DER could be at least half of the future energy system. However, they still aren't being given equal priority by Australia's energy market institutions or energy ministers. Given that DER also have inherent resilience benefits, we should be doing everything we can to integrate as many DER into the system as fast as we can as the climate changes. The South Australian system black in 2016 showed how vulnerable large-scale electricity systems are to extreme weather events, with severe winds damaging 23 pylons on transmission lines. DER are not immune from extreme weather risk, but their distributed nature, particularly when incorporating storage, and especially in the mobile form of electric vehicles, makes systems that prioritise DER more resilient.

Australia – ahead of the world on rooftop solar, lagging on EV integration

Australia is leading country globally in rooftop solar when measured in watts per capita. So far in the National Electricity Market (NEM), there is:

- over 24 gigawatts (GW) of rooftop solar (RTS)
- an estimated 15 GW from over 3 million household rooftop solar systems – around 1 in 3 homes have solar (close to 50% in South Australia and Queensland)
- an estimated 9 GW from over 400,000 business (commercial and industrial (C&I)) rooftop solar installations, and growth in this sector is accelerating, and
- over 180,000 household batteries (Sunwiz estimates – 140,000 of these are recorded in the Clean Energy Regulator's database).

This means to date households and businesses have invested well over $25 billion in DER.

In the 12 months to 9 August 2024, 38% of demand in the NEM was met by renewables. Of this, RTS met 11%, which was slightly less than wind (12%) and more than utility-scale solar (7%) or hydro (8%). RTS met over 11%

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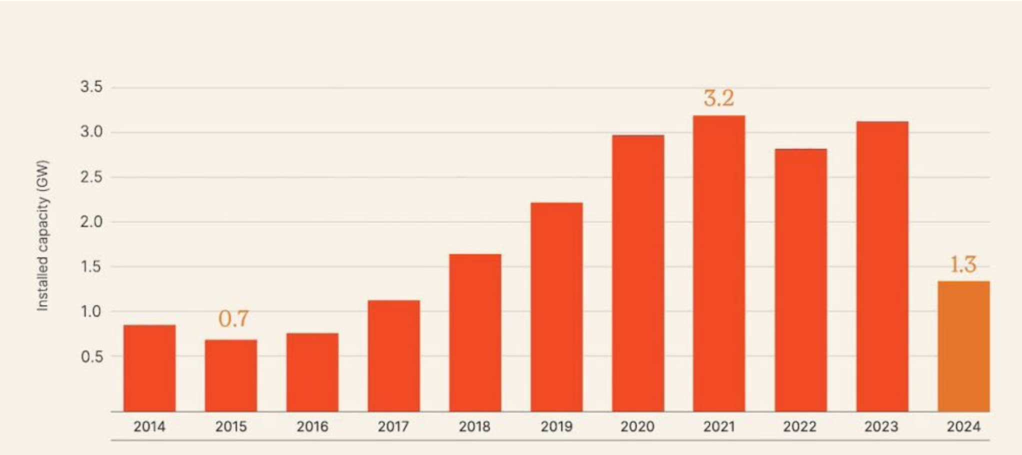
[1] Anna Collyer (9 October 2023), Consumers the hero on the road to net zero [speech to the Financial Review Energy and Climate Summit]. Accessed 28 January 2025.

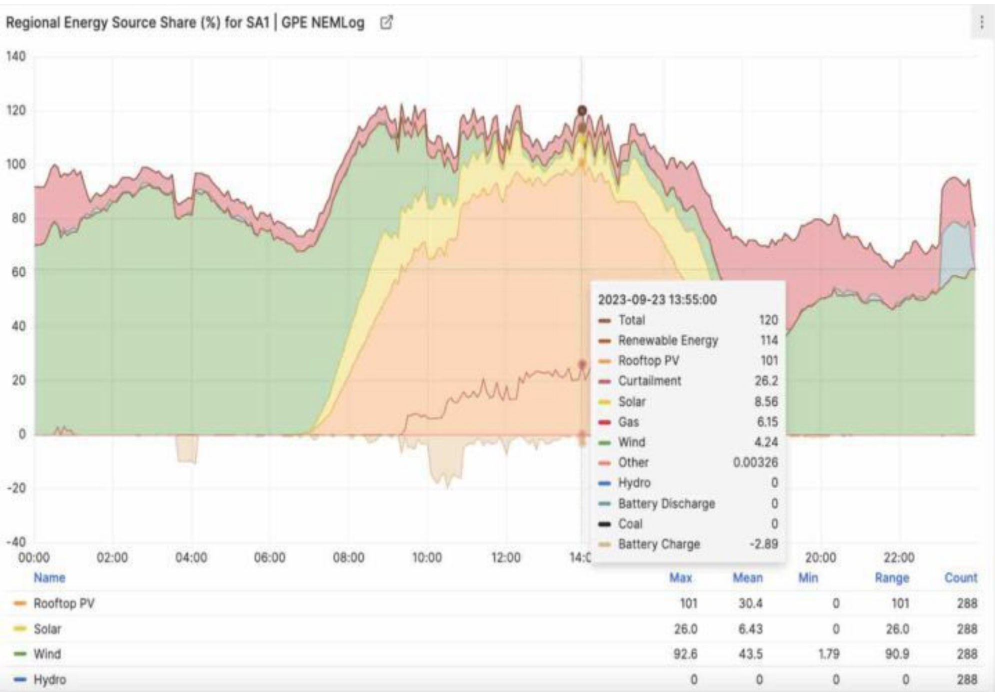
of demand in the NEM, slightly less than wind (12%) and more than utility-scale solar (7%) of 38% renewable supply.[2] The contribution of rooftop solar varies by season. For example, RTS contributed more electricity to the NEM in the first quarter of 2024 (13%) than each of grid-scale solar, wind, hydro or gas did individually.[3]

***Figure 1:* Installed rooftop solar capacity by year[4]**



Rooftop solar is now capable of meeting at least half of underlying energy demand across the NEM in the middle of a sunny day.[5] RTS is also the main reason why prices are increasingly negative in the National Electricity Market. Over the 12 months to 30 August 2024, negative prices were experienced in 22% of all price intervals in South Australia, 19% in Victoria, 14% in Queensland, 7% in NSW and 3% in Tasmania.[6]

***Figure 2:* Electricity generation by source in South Australia on 23 September 2023[7]**



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[2] Open Electricity, Energy Consumption. Accessed 28 January 2025.
[3] Ibid.
[4] Clean Energy Council (2024), *Rooftop solar and storage report January—June 2024.*
[5] Renew Economy, Rooftop solar supplies more than 50 per cent of main grid's power demand for first time. Accessed 28 January 2025.
[6] Pers. Comm. Dr Dylan McConnell at UNSW.
[7] Published in Parkinson, Giles (2023) Rooftop solar meets all of South Australia demand in major new milestone, RenewEconomy, graph from GPE NEMLog2.

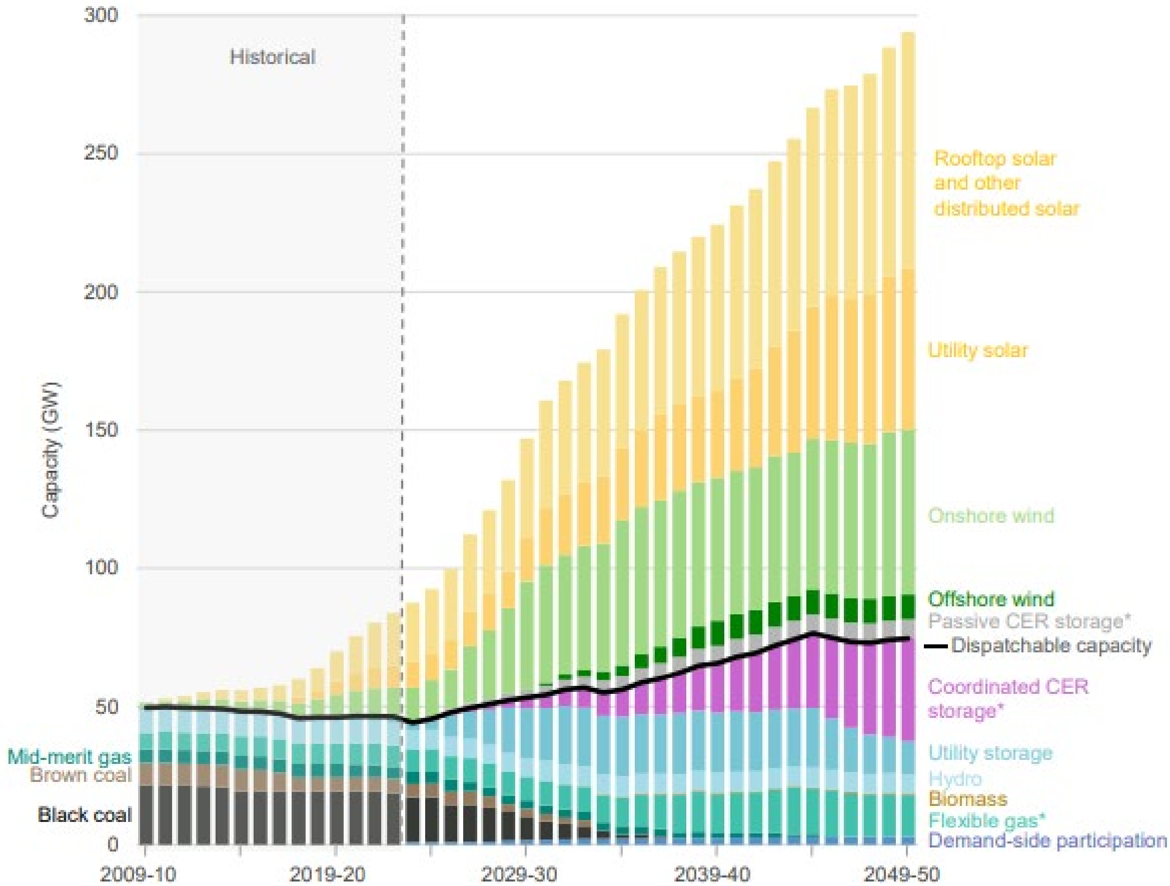
Occasionally the entire state of South Australia is fully supplied with electricity by RTS. This first occurred on 23 September 2023, when RTS supplied 101% of South Australian electricity (see Figure 2).

What AEMO's 2024 Integrated System Plan says about the future of DER

In the Australian Energy Market Operator's (AEMO) Integrated System Plan (ISP) [8], the Step Change scenario meets Australia's 43% emission reduction by 2030 commitment, and projects that by 2050:

- RTS and other distributed solar (primarily ground-mounted) will be the largest source of generation capacity at 86 GW (30% of a total of ~290 GW)
- there will be a four-fold increase in rooftop solar capacity alone to 72 GW (AEMO's current estimate of RTS is lower than this paper)
- 79% of households will have rooftop solar
- 56 GW/660 gigawatt hours (GWh) of storage capacity will be needed
- there will be an almost four-fold increase to 49 GW/646 GWh of dispatchable storage
- coordinated consumer energy resources (CER) storage will be 37 GW (66%), with 34 GW (61% of what's needed) in behind-the-meter (BTM) batteries at residential and commercial premises, up from an estimated 1 GW in 2024, and that
- electricity consumption will roughly double to over 410 terawatt hours (TWh) in 2049–50.

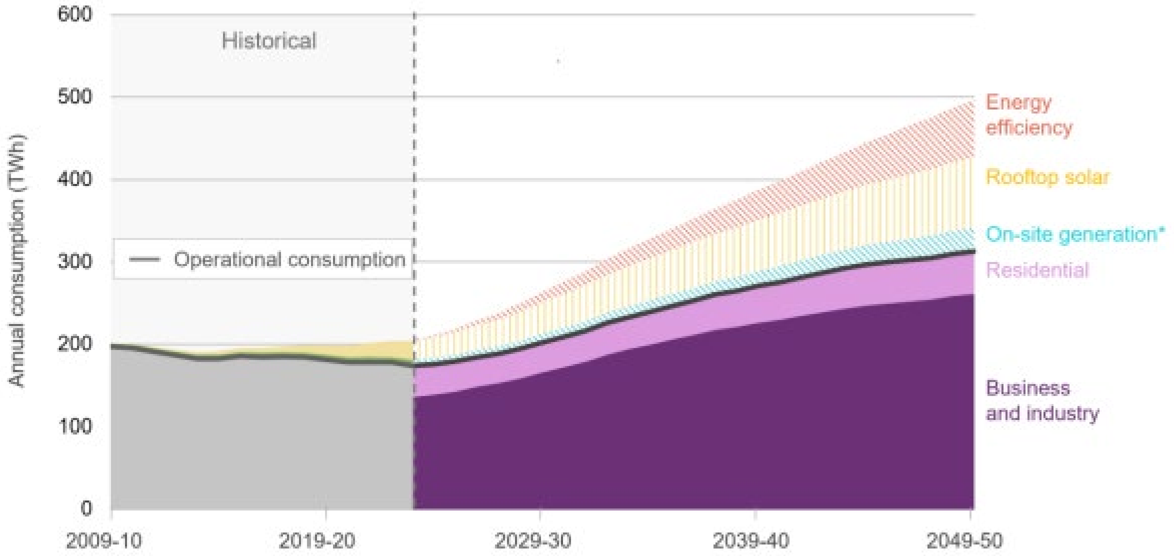
Figure 3: ***2024 ISP Step Change scenario – projected capacity*** [9]



[8] Australian Energy Market Operator (AEMO) (2024), 2024 Integrated System Plan. Accessed 28 January 2025.
[9] Ibid.

As a result, electricity demand increases from electrification will be partly offset by increases in RTS, as the following figure shows.

***Figure 4:* NEM residential electricity consumption, 2024 ISP**[10]



However, even AEMO's 2024 ISP step change scenario is conservative in several respects and underestimates the likely role of DER. For example:

- AEMO does not account for the likely increase in PV panel power density,
- AEMO does not take into account that the Australian Renewable Energy Agency (ARENA) is aiming for utility-scale solar to be 30 cents per watt by 2030, 75% lower than the current cost of about $1.20 per watt, and
- AEMO does not assume any vehicle-to-grid (V2G) capacity before 2030 and appears to have underestimated the longer-term future capacity of V2G.[11]

The federal Minister for Climate Change and Energy, Chris Bowen, lodged a rule change request in June 2024 asking the Australian Energy Market Commission (AEMC) to make a rule to direct AEMO to improve its consideration of demand-side factors in the ISP, including assumptions about the uptake and orchestration of CER and distributed resources.[12]

On 26 September 2024, the AEMC published a draft determination and a more preferable draft rule, which would:

- require AEMO to publish a demand-side factors statement in the ISP to provide a transparent and consolidated explanation of the expected development of the distribution network and the demand-side of the market
- require AEMO to publish information guidelines to drive a more consistent approach to the collection of relevant information
- place an obligation on distribution network service providers (DNSPs) to provide relevant information, and
- require AEMO and DNSPs to publish certain DNSP data.[13]

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[10] AEMO (2024), 2024 Integrated System Plan. Accessed 28 January 2025.

[11] Kuiper G and Bowyer J (2 May 2024), Integrated System Plan needs greater ambition on DER to be a true whole-of-system plan, Institute for Energy Economics and Financial Analysis (IEEFA). Accessed 28 January 2025.

[12] Minister for Climate Change and Energy (May 2024), Rule Change Request [PDF]. Accessed 28 January 2025.

[13] Australian Energy Market Commission (AEMC), Improving consideration of demand-side factors in the ISP. Accessed 28 January 2025.

In theory, this rule change will lead to improvements in the assumptions made around CER/DER in the ISP and in the interaction between the plans of DNSPs and the ISP. Energy Networks Australia (ENA) has also called for a review of inclusion of distribution in the ISP and for AEMO to work with distribution networks to 'to consider the range of options for contribution of distribution networks in the 2026 ISP, and to co-optimise between large scale and small scale in developing an optimal development pathway'.[14] There is considerable potential here to think about electricity planning from the bottom up, as well as from the top down. To do so with a place-based approach, considering the electrification of reticulated gas and transport, changes to urban form, and resilience in a changing climate, is likely to be effective and efficient.

DER as the Swiss army knife of energy technologies

Especially when aggregated, DER, like a Swiss army knife, can provide multiple services to an electricity system. These include services:

- to the whole (or 'bulk') power system – that meet the requirements of the transmission system and can assist in balancing supply and demand (reliability) and maintaining frequency and other essential system (security) parameters
- to the distribution system – known as network support services in Australia, flexibility services in Britain and non-wires solutions in the US, and
- to the edge of the grid, including managing microgrids and islanded grids.

These are outlined in a US context in Figure 5 by the Rocky Mountain Institute (RMI) for the National Association of Regulatory Utility Commissioners and the National Association of State Energy Officials.[15]

***Figure 5:* Grid services able to be provided by aggregated DER[16]**

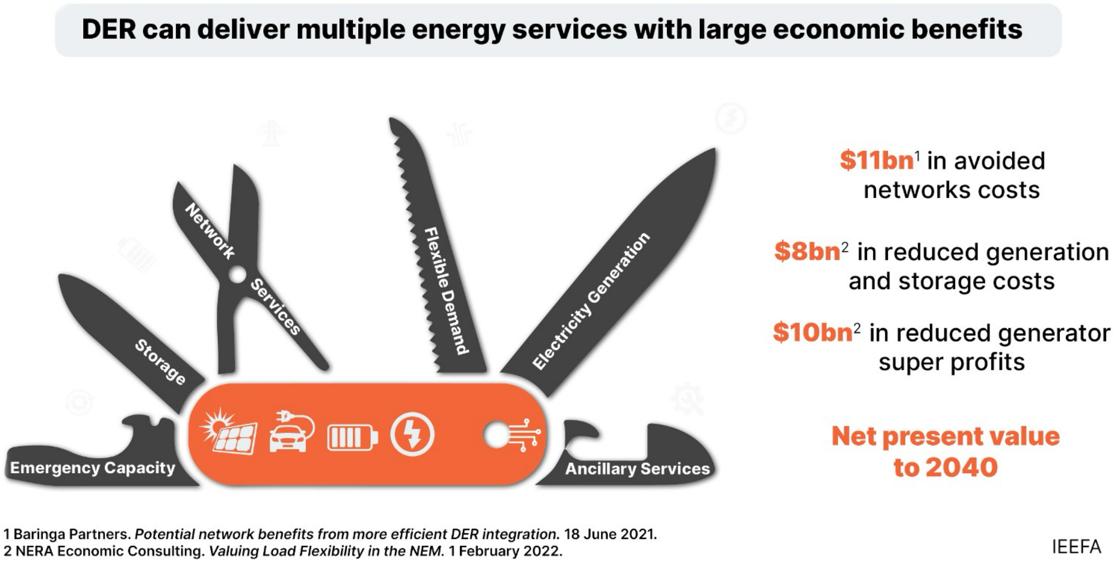
[14] Energy Networks Australia (6 August 2024), The Time is Now: Getting smarter with the grid. Accessed 28 January 2025.
[15] National Association of Regulatory Utility Commissioners and National Association of State Energy Officials (July 2024), *Aggregated Distributed Energy Resources in 2024: The Fundamentals*.
[16] Ibid.

RMI's report highlights that aggregated DER (ADER, often known as virtual power plants or VPPs) require advanced or smart inverters to provide certain essential reliability grid services, and that the need for grid services will evolve as the grid transitions toward renewables and ADERs.

$19 billion in benefits

A meta-analysis of the studies of the economic benefits of DER to the NEM by the author found that they could deliver at least $19 billion in net present value by 2040.[17] This included $11 billion in reduced transmission and distribution augmentation and replacement costs and $8 billion in reduced large-scale generation and storage costs. However, the studies, undertaken by NERA Economic Consulting and Baringa Partners, did not include benefits in terms of ancillary services, emergency capacity and resilience. In addition, these studies were based on now outdated, more conservative figures on DER uptake than those in the 2024 ISP, so the actual benefit could be higher. In addition to the whole-of-system benefit, NERA identified a further potential consumer benefit of $10 billion in reduced generator super-profits through the smart, flexible use of DER.

***Figure 6:* Estimated benefits of DER to the NEM**[18]



VPPs/ADER have the potential to participate in several Australian energy markets, including:

- the wholesale energy market and the wholesale demand response mechanism
- Frequency Control and Ancillary Services (FCAS) markets
- the Reliability and Emergency Reserve Trader (RERT), and
- providing distribution network support services, among them thermal, voltage or peak-demand management.

At present, aggregated DER can participate in contingency FCAS markets; within very narrow criteria, aggregators of large commercial and industrial assets can participate in the wholesale demand response mechanism, and a draft determination by the AEMC on 25 July 2024 has flagged allowing aggregated DER to be scheduled and dispatchable in the wholesale market.[19]

[17] Kuiper G (15 February 2024), DER could provide $19 billion economic boost by 2040, IEEFA. Accessed 28 January 2025.
[18] Ibid.
[19] AEMC, Integrating price-responsive resources into the NEM. Accessed 28 January 2025.

Why engineering is so important to DER integration

Fundamentally, the business model of distribution networks has not changed since they were first developed and designed to deliver electricity to homes and businesses over a century ago. Distribution networks were considered 'a passive termination of the transmission network with a radial structure, unidirectional power flows, and a simple and efficient protection scheme'.[20]

> *'A one directional electricity grid – with power coming from a few, large, faraway power plants – delivered affordable and reliable energy through a "set and forget" design. Such a grid can be well designed largely through effective planning, and relatively static customer behaviour enabled planning to work off reliable assumptions. Technology, specifically low-cost solar panels, changed all that.'*[21]

Rooftop solar, battery storage, electric vehicles and other DER are changing the magnitude, variability, and direction of power flows in electricity networks. What was perhaps the least glamorous part of an electricity system, the lowest voltages, are now where the greatest challenges and opportunities are. While the physics remains the same, ensuring the system operates within thermal, mechanical and electrical limits, the complexity of the power flows, even at a feeder level, requires a revolution in the operation of the distribution networks.

The operation of the distribution system is going from being a largely static and mechanical operation to a dynamic one where digitalisation and data flows are crucial. In the distribution networks, power systems engineering now involves a growing amount of software development and data science (including machine learning, artificial intelligence (AI) and cybersecurity), as well as power electronics. This combination of approaches used to be known as a 'smart grid' but is increasingly just called 'grid modernisation'. Therefore, multiple kinds of engineering, including interdisciplinary engineering, is required for the potential of DER integration to be fulfilled. In the author's view, this is the most exciting and interesting part of the energy transition.

Fundamentals: low-voltage network visibility and data streams

Until recently, distribution network operators did not need to know anything about the operational performance of the low-voltage network on hourly or daily timeframes. [22,23] Now, greater visibility of low-voltage (LV) network conditions, including the location and operation of DER, is critical to both the operation and planning of distribution networks.[24]

Solar Analytics' DER Visibility and Monitoring Best Practice Guide lists common sets of static and dynamic data for eight use cases, compiled in consultation with industry – see table 1.

The first two of these use cases are useful on operational timescales of minutes to days. The third and fourth use cases are useful for scheduling and planning timescales of days to months or a few years, and the fifth and sixth use cases are useful for the long term – developing future capability.

Visibility and data flows can be provided in three primary ways: smart meters, phasor measurement units (network monitors), and customer energy monitoring and management systems (including data from solar and

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[20] Mokryani G (2022), Future Distribution Networks: Planning, Operation, and Control (Chapter 1), AIP Publishing LLC. Accessed 28 January 2025.

[21] Braslavsky J, Graham P, Havas L, Sherman J, Spak B, Dwyer S, Langham E, Nagrath K, Orbe JG, Khorasany M, Razzaghi R, Heslop S, Hossain J, Ibrahim I and Amin R (November 2021), Low voltage network visibility and optimising DER hosting capacity: Final Report, RACE for Networks Program, Project Code: 20.N2.A.0126, ISBN: 978-1-922746-11-5

[22] Ibid.

[23] Ibid.

[24] International Energy Agency (25 May 2022), Unlocking the Potential of Distributed Energy Resources: Power system opportunities and best practices p.55. Accessed 28 January 2025.

battery inverters). Each of these sources has challenges in terms of ensuring data quality, consistency and integration, managing cybersecurity vulnerabilities, procurement costs, and transparency.[25]

***Table 1:* Low-voltage visibility value streams[26]**

Issue	Value stream	Parameters required (at NMI)	Measure interval	Update rate	Sampling density
1.	Network state estimation and performance	Voltage (assumes voltage and current available at substation)	5-10 min	Real time (could be monthly)	>2% of premises, greater fidelity at higher density, ideally 75% of "nodes"[6]. 20% required for MV.
2.	Fault identification	Voltage and current	1-5 min	Real time	>2% of premises. Note millisecond likely required for broken neutral
3.	DER hosting capacity	Voltage, Active/Reactive Power generated and consumed	5 min	Monthly	2 sites per feeder, with greater certainty/ redundancy from greater coverage
4.	DER compliance	Active/Reactive Power generated, Voltage	5-10 min	Monthly	>20% DER, with greater accuracy and compliance at near 100% coverage
5.	Constraint management	Capacity, Voltage Active/Reactive Power generated and consumed	10s – 5 min	Real time	Participating DER
5.1	Constraint reporting	Capacity, Voltage Active/Reactive Power generated and consumed	10 min	Weekly/ Monthly	At least 1 customer per LV feeder, more increases accuracy
6.	Orchestrating DER	Capacity, Voltage Active/Reactive Power generated and consumed	10s – 5 min	Real time	Participating DER. Note that full orchestration will require 1min or better

Currently there is only 100% smart meter penetration in the state of Victoria, where the networks have near full visibility to the connection point (see table 2).

Two Australian startup companies have developed means to increase the visibility of LV networks through smart software. GridQube provides near real time visibility of the two-way operational state of distribution networks using state estimation and Gridsight's hosting capacity software has similar features, including being able to verify the installed capacity, compliance and location of behind-the-meter DER. There is doubtless more innovation to come in this space where data science meets AI meets power electronics.

AEMO has a DER register, but it only currently provides limited information on generation assets, batteries and demand-side participation data provided to AEMO by Registered Participants, and only aggregated information is available publicly.

In Germany, the Federal Network Agency (the Bundesnetzagentur) is required by law to operate the Market Master Data Register, which has no minimum size limit for DER and includes, for example, solar installations on

[25] Mokryani G (2022), Future Distribution Networks: Planning, Operation, and Control (Chapter 1), AIP Publishing LLC. Accessed 28 January 2025.
[26] Solar Analytics (May 2020) DER Visibility and Monitoring Best Practice Guide [PDF]. Accessed 29 January 2025.

balconies, carports, garage walls and roofs; EV chargers; and heat pumps. The data collected includes location (by postcode and place), generation/load type, nominal power and gross performance, and commissioning date.

***Table 2:* State of network visibility by DNSP 2019**[27]

DNSP		MV	LV		Behind meter		
		Zone substation feeder	Distribution transformer	LV feeder	Customer connection	Inverter exports	Customer consumption
SA	SA Power Networks	80%	3.4% ↑	↑	0.1% ↑	0.0%	
QLD	Energex	100%	40% ↑		1.5% ↑		
	Ergon Energy	95%	3.5% ↑				
WA	Western Power	100%	1.0% ↑	↑	5.0% ↑		
VIC	Citipower and Powercor	100%	99% ↑	99%	99%		
	United Energy	100%	100%	100%	100%		
	AusNet Services	100%	98%	98%	98%	↑	↑
	Jemena	100%	98%	98%	98%		
NSW/ACT	Ausgrid	100%	17% ↑	24% ↑	9.0% ↑	0.5%	0.5%
	Evoenergy	100%	3.0%	10% ↑	↑	3.3% ↑	3.3% ↑
	Endeavour Energy	95%	1.8%		15% ↑	0.05%	
	Essential Energy	85%	0.014% ↑		7.0% ↑	7.0%	

Bar and value indicate level of visibility; upward arrow indicates increasing trend. Source: image from AEMO, Renewable Integration Study Stage 1 Appendix A: High Penetrations of Distributed Solar PV, 2020. Derived from detailed DNSP responses to AEMC LV network visibility survey.

Thanks to the University of Technology Sydney and ENA, there are now publicly available Network Opportunity Maps. These include data layers to the zone substation level on current and forecast:

- capacity
- available distribution capacity
- load
- proposed investment
- annual deferral value
- peak day available capacity
- new generator connection capacity (transmission or distribution powerlines or substations).

However, these data layers are not publicly available below the zone substation level. Ideally, every LV feeder would be mapped and its key characteristics made publicly available to assist energy consumers and industry, particularly businesses planning rooftop solar, battery energy storage systems and EV charging.

In turn, networks would prioritise decentralised management and protection. We are still learning how to develop and use big data sets to manage distribution networks. The development of data science – the analytical and computational tools to manage distribution networks – is vital and likely to take a decade in Australia.[28] Ensuring accurate data is vital and requires not only 'smart' meters but also smarter uses of other data sources, including inverters and data from telecommunications infrastructure.

The Energy Security Board identified a slightly different range of data sets of interest to a broader range of stakeholders (see figure 7), but it is unclear how the Australian Energy Regulator (AER) has taken the development of these forward. Another outstanding question is to what extent distribution networks need data or 'intelligence'

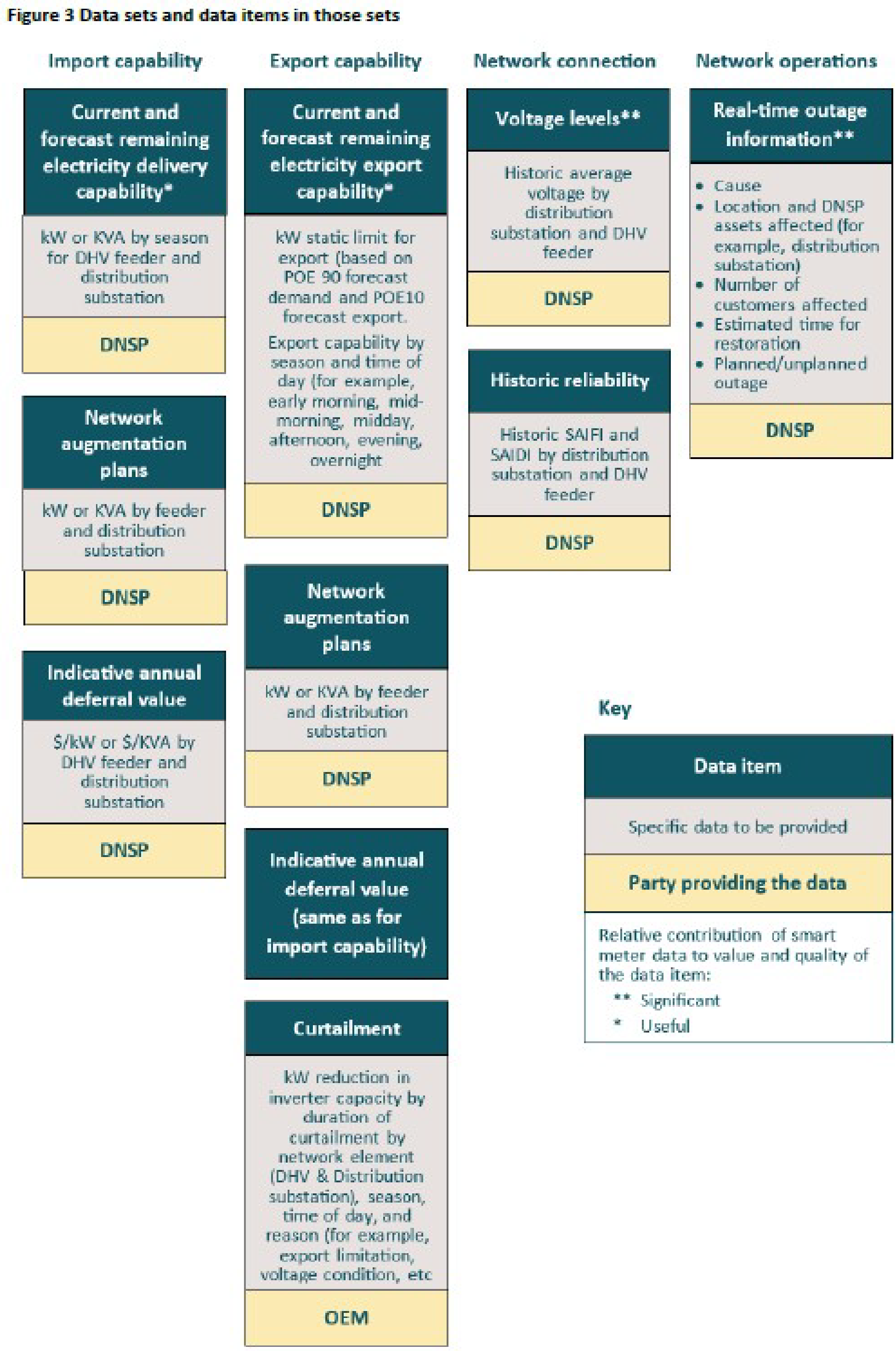
[27] AEMO data included in Mokryani G (2022), Future Distribution Networks: Planning, Operation, and Control (Chapter 1), AIP Publishing LLC. Accessed 28 January 2025.

[28] Thanks to Anthony Seipolt of Cadency Consulting and Dr Baran Yildiz at UNSW for emphasising the role of data science in the future of distribution networks to me.

about what is happening behind the meter or at a consumer's site and to what extent AI might be able to assist with forecasting generation and load behind the meter.

There are many issues to be resolved in terms of data collection and data flows in LV networks, and no government body or energy market institution has been tasked with resolving them. This is one of many areas that would benefit from engineers engaging with energy market policymakers and regulators.

***Figure 7:* Distribution network data sets and data items**[29]

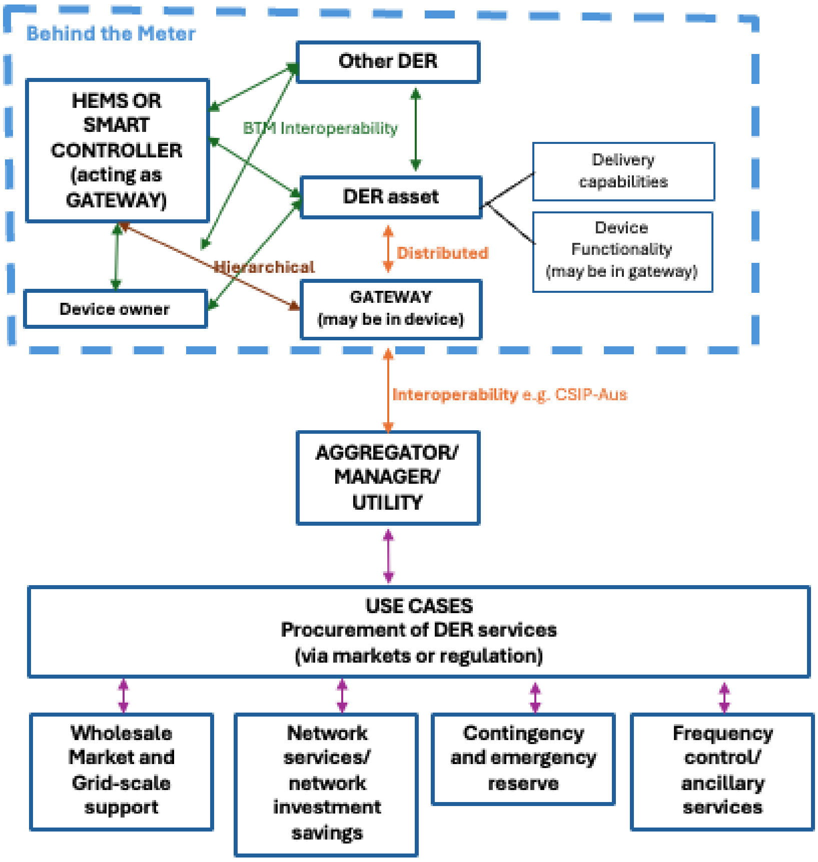


[29] Energy Security Board (ESB) (2023), Benefits of increased visibility of networks (Consultation paper) [PDF]. Accessed 29 January 2025.

Fundamentals: Communication by DNSPs with a DER

Beyond visibility, DNSPs and aggregators need to be able to communicate with a gateway at the connection point, which may be in a DER device, such as a smart inverter, or in a controller, such as a home energy management system (HEMS).

Figure 8: ***The interaction between DER, the gateway and use cases***



A group of academics, DNSPs and industry practitioners collaborated as the DER Integration API Technical Working Group to develop the Common Smart Inverter Profile (CSIP-Aus) interoperability standard/communication protocol based on IEEE 2030.5-2018 and the Common Smart Inverter Profile (CSIP) which has been adopted voluntarily by several DNSPs for dynamic operating envelopes (discussed in the section below).

The inverter standard itself (AS 4777.2:2020) is in the national electricity rules[30] but Australia does not currently have a body which can set DER technical standards, despite five years of consultation on the topic.[31] The National Consumer Energy Resources Roadmap states that legislation for a national regulatory framework for CER to set and enforce standards will be drafted in 2025 and a regulator established in 2026.

The lack of a body to set DER technical standards is one example of how energy market institutions have failed to recognise the growth and significance of DER or value its role in decarbonising the NEM. This may indicate insufficient engineering understanding, especially within the AEMC.[32]

[30] AS/NZ 4777.2:2020 includes voltage-reactive power control (Volt-Var) and voltage-active power control (Volt- Watt) functions enabled by default and configured by region. The standard also includes the requirement to include ride-through performance to ensure the inverter stays connected to and synchronised with the system during system disturbances.

[31] Kuiper G (10 October 2023), The wasted years on governance arrangements for DER technical standards, IEEFA. Accessed 29 January 2025.

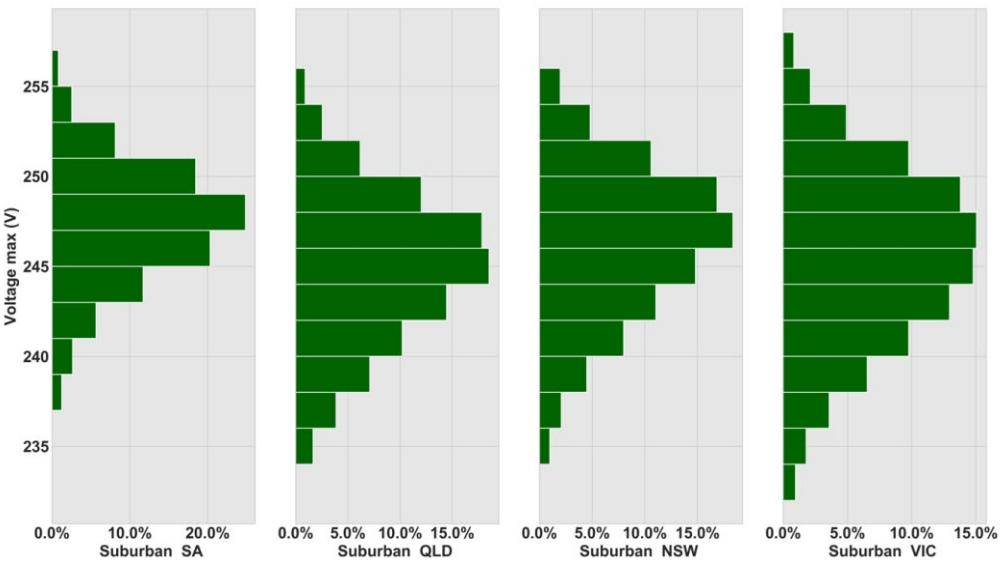
[32] Ibid.

Fundamentals: voltage management

The lack of attention to distribution network voltages is another deficiency in the current regulation of the NEM. Exports from solar systems can increase voltages in LV networks. Around 2019 there was significant industry chatter that rooftop solar was causing high voltages in distribution networks and that this was going to result in localised blackouts and significant costs to consumers, including through upgrades to the grid. As a result, the Energy Security Board commissioned the University of New South Wales (UNSW) to examine the state of voltages across the NEM using 12,000 data points from Solar Analytics. [33] This analysis found that voltages were running above the 230V NEM standard 95% of the time and often significantly above the standard, as shown in figure 9.

Many sites recorded higher voltages during the night, highlighting that rooftop solar was not the cause of the high voltages. The high voltages – an average of close to 245V – were in fact an existing issue related to management of the distribution networks. They were a result of operational procedures developed in response to large air-conditioning loads being installed in the 2000s and 2010s and a slow move by the DNSPs from the previous 240V standard to the 230V standard, which was officially changed in 2000 (except for Queensland).

***Figure 9:* UNSW voltage analysis in four NEM regions**[34]



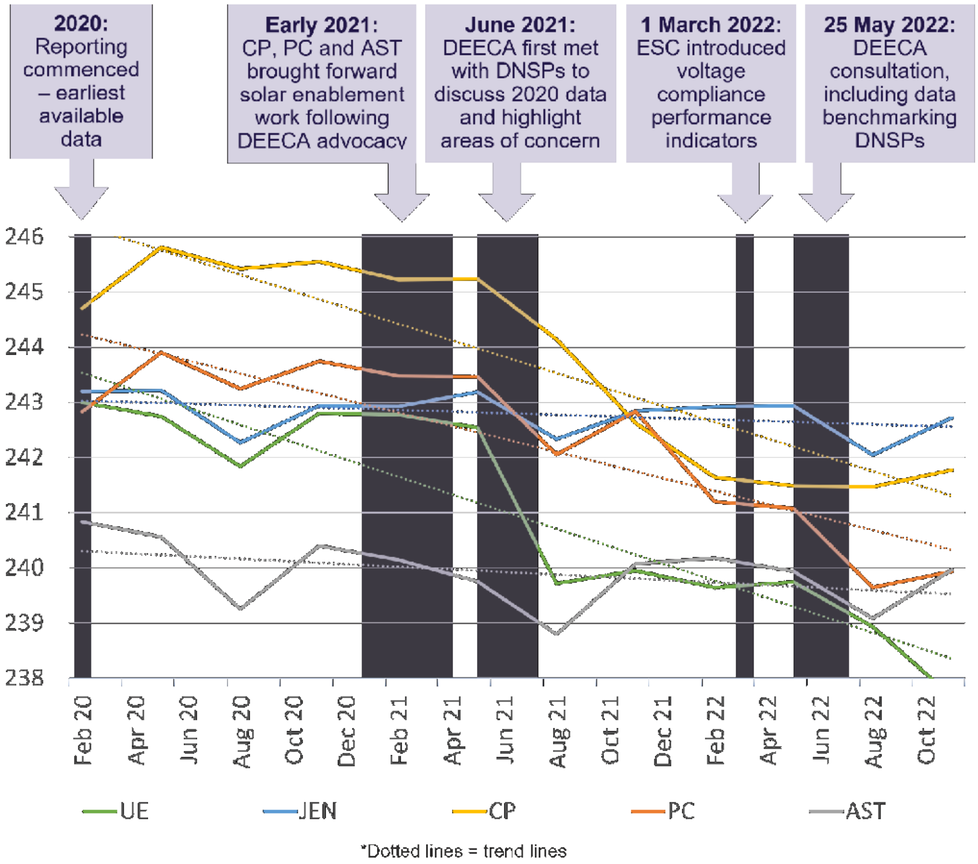
Rooftop solar was not the cause of over-voltages but was in fact a victim of it, as rooftop solar systems trip when the network voltage reaches 258V, which was happening more than was necessary. More importantly, consumers were paying for more electricity supply than needed as a result of the high voltages and the lifetime of their appliances was being reduced. A University of Wollongong study concluded that there is a 25% reduction in equipment life when consistently supplied at 253V rather than 230V.[35] Indeed, the University of Wollongong estimated a 5% voltage reduction would deliver $1.91 billion per annum and $283 per NEM customer per year in bill reduction, as well as reducing 3.07mt CO_2-e in greenhouse gas emissions each year.[36]

The Victorian Government and the Victorian electricity regulator, the Essential Services Commission have asked in response to the UNSW evidence. As a result of their actions and those of the Victorian DNSPs, shown in the

[33] University of New South Wales (May 2020), Voltage Analysis of the LV Distribution Network in the Australian National Electricity Market. Accessed 29 January 2025.
[34] Ibid.
[35] Christopher T (n.d.), ENERGY Efficiency and Overvoltage: The Hidden Electricity Thief [Presentation to Engineers Australia Climate Smart Engineering, 2021] [PDF]. Accessed 29 January 2025.
[36] Ibid.

figure below, average voltages are now falling across all time periods, including the middle of the day, the peak solar generation period.[37,38]

***Figure 10:** Average voltage by DNSP and main Victorian Government actions*[39]



The Victorian Government has recommended that, among other steps, the voltage standard AS 61000.3.100 be updated to allow for a 10% tolerance for both under- and over-voltage; transparency of low voltage network data be improved; and notification and compensation provisions for voltage excursions be reviewed. Unfortunately, the National Consumer Energy Resources Roadmap does not seem to have incorporated this advice and only plans to 'examine costs and benefits of improving voltage management across distribution networks to lower costs for consumers', while 'consideration of costs and benefits to determine best approach for consumers, to improve network voltage management' is noted as 'future work'.[40] This work is urgent in order to reduce consumer bills.

Rooftop solar exports will impact voltages in the distribution networks more as solar production increases. A simplified hosting capacity assessment of a zone substation area in Brisbane (assuming that not more than 5% of the low voltage feeders in the network model should exhibit voltages exceeding either of the upper or lower statutory limits on any of their phases) indicated that, shortly after 2030 in the 2022 ISP's Step Change scenario,

[37] Essential Services Commission (n.d.), Voltage performance data. Accessed 29 January 2025.

[38] When DNSP voltages are consistent with the standard 230 volts, the Victorian Government estimates Victorian electricity consumers will save over $30 million in ongoing additional consumption savings per annum. This figure only represents savings from decreased electricity consumption, it does not include savings from reduced appliance degradation or improved solar exports – so the potential savings on offer are even higher.

[39] State of Victoria Department of Energy, Environment and Climate Action (2023), Voltage Management in Distribution Networks [Directions Paper].

[40] Energy and Climate Change Ministerial Council (2024), National Consumer Energy Resources Roadmap: Powering Decarbonised Homes and Communities [PDF], Department of Climate Change, Energy, the Environment and Water. Accessed 29 January 2025.

the distribution network will reach its hosting capacity at noon due to solar PV-induced over-voltages. [41] The researchers inadvertently found thermal limit violations are likely to become a more severe and rapidly emerging issue than over-voltages around noon under high solar day conditions.[42] The good news is that the researchers found on-load tap changes and especially distribution-scale static synchronous compensators (dSTATCOMs) are a cost-effective solution for over-voltages, and battery energy storage systems (BESS) are likely to be effective for addressing thermal limits.[43] The scale of the relative costs and benefits of the various solutions is clear from the final result of the cost-benefit analysis in the table below.

***Table 3:* Cost-benefit analysis of investigated voltage management technologies for suburban distribution networks**[44]

Voltage Management Solution/Scenario	Cost ($AUD)	Annual CECV ($AUD)	Annual CECV Benefit ($AUD)
BAU with thermal upgrades	0	3,555	0
Curtailment reconductoring	11,145,753	3,216	339
One STATCOM per LV area	78,000	1,700	1,855
Multiple STATCOMs per LV area	169,000	1,241	2,314
OLTCs	340,000	1,519	2,036

Fundamentals: dynamic operating envelopes/flexible exports

Given the lack of visibility at the LV level and traditional conservative approaches to network operation, DNSPs have generally set the export limit for household solar systems to 5kW per phase. However, as the average household RTS system is now over 8kW, these static limits can curtail the contribution of RTS to the grid, especially for homes that are empty during the day, and so reduce the return on investment for these households.

Fortunately, SA Power Networks recognised the inefficiency of a static export limit and developed software which forecasts hosting capacity 24 hours in advance, on a five-minute basis, and sends a dynamic operating envelope (DOE), as it is technically known, of 'flexible export' limit of up to 10kW to solar inverters.[45] SA Power Networks modelling shows this DOE will bind below this doubled limit only 2% of the time or approximately 50 daylight hours per year.[46]

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[41] Razzaghi R, Burstinghaus E, Gerdroodbari YZ, Hibbert M, and Liu J (2023). Investigation into Voltage Management Technologies for Future Australian Suburban Distribution Networks [PDF]. Prepared for RACE for 2030 CRC. Accessed 29 January 2025.

[42] Ibid.

[43] Ibid. Note benefits were calculated using the customer export curtailment value (CECV) metric created by the AER. The CECV represents the value of alleviating the curtailment of solar energy so that it is delivered to the network.

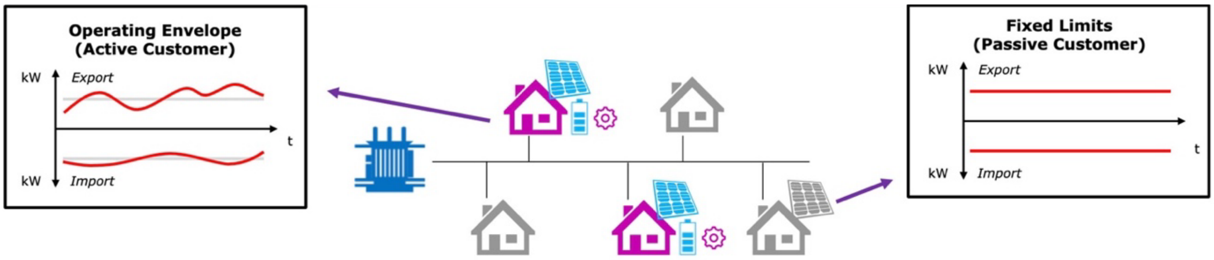
[44] Ibid.

[45] The definition according to the DEIP DOE Working Group is: "Operating envelopes represent the technical limits within which customers can import and export electricity. Dynamic operating envelopes vary import and export limits over time and location based on the available capacity of the local network or power system as a whole." From Australian Renewable Energy Agency (July 2021), DEIP Dynamic operating envelopes workstream [PDF]. Accessed 29 January 2025.

[46] SA Power Networks. (2024, January). Business case: CER integration 2025-2030 Regulatory Proposal Supporting document 5.7.4.

This innovative software means solar households in South Australia have the potential to double their exports, and potential earnings from those exports, 98% of the time. Implementation of flexible exports was achieved for $32 million – less than 1% of SA Power Network's $3.9 billion five-year revenue.[47]

Figure 12: ***Dynamic operating envelopes compared with fixed limits***[48]



In July 2022, consultants Cutler Merz found most DNSPs plan to incorporate DOEs into their connection agreements with their wider customer base within the next five years.[49] Energy Queensland (via Energex and Ergon Energy) is using a different name ('dynamic connections') and a different limit of 10kVA.[50] Other DNSPs have run trials, including Project Converge (Evo Energy), Project Symphony (Western Power), Project Edith (Ausgrid), and Project Edge (AusNet).

This highlights two issues: there is no harmonisation, with several different approaches to the definition, publication, communication and enforcement of DOEs underway; and a software innovation that could substantially increase consumers' earnings from their DER has not been implemented across the NEM, and there is no compulsion for all DNSPs to do so. Given the benefits, DOEs should be the default offer for consumers, with flat export rates as opt-in.

In October 2022, the AER to released its flexible export limits issues paper for consultation. On 31 July 2023, the AER released its response to the flexible export limits issues paper consultation, which included a priority action to initiate 'a rule change proposal to provide the AER with the appropriate head of powers to develop and publish a binding Export Limit Guideline governing methodologies for export capacity allocation and provision of information to consumers'.[51] On 17 November 2023, the AER published the draft export limit interim guidance note for consultation. On 23 October 2024, almost a full year later, the AER published the final guidance note.[52] This guidance note provides no means of ensuing consistency, however, and the priority action to initiate a rule change proposal, almost 15 months ago, has not been completed. Instead, 'Over the next 12 months, the AER intends to monitor DNSP adherence to the guidance note to determine whether it has been effective in addressing identified problems and promoting the intended policy outcomes.'[53]

Meanwhile, the National Consumer Energy Resources Roadmap released in mid-2024 states that 'Fast track implementation of flexible exports component of dynamic operating envelopes (DOEs) by network operators to enable increased CER flexibility, third party participation and maximise benefits to the system and customers' will be completed in 2025. Here we have yet another example of the need for engineers to engage with policymakers and regulators to ensure that technology that supports the integration of DER is implemented in a timely manner.

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[47] Bowyer J and Kuiper G (June 2021), A grid dominated by wind and solar is possible: South Australia: a window into the future [PDF]. IEEFA. Accessed 29 January 2025.

[48] Melbourne Energy Institute. (2024). Operating envelopes compared with fixed limits. University of Melbourne.

[49] CutlerMerz (July 2022), Review of dynamic operating envelope adoption by DNSPs [PDF]. ARENA. Accessed 29 January 2025.

[50] Energex (n.d.), Dynamic connections for energy exports. Accessed 29 January 2025.

[51] Australian Energy Regulator (AER) (31 July 2023), Review of regulatory framework for flexible export limit implementation decision. Accessed 29 January 2025.

[52] AER (October 2024), Export Limits Guidance Note [PDF]. Accessed 29 January 2025.

[53] AER (October 2024), Export Limits Guidance Note - Explanatory Statement. Accessed 29 January 2025.

Evolution: DER providing network support services

Individual or, more usually, aggregated DER can substitute for augmentation or replacement within existing networks, such as by easing congestion on demand. The provision of network support services is well-established in the UK (where it is known as flexibility procurement), and it is emerging in a number of other European countries and parts of the US, where it is termed 'non-wires solutions'. There have been trials of household DER providing network services in Australia, with Projects Networks Renewed, CONSORT (Bruny Island Battery Trial), Edge, Edith and Symphony, and a 'flexibility services' pilot in WA using commercial and industrial DER. [54,55,56,57,58]

Of these, Ausgrid's Project Edith is the most interesting, as it is trialling dynamic, locational, short-run marginal cost distribution network pricing. The project includes:

- 'a pricing engine that can calculate dynamic network pricing considering internal (load measurements, metering data, network connectivity) and external (weather, aggregator operation) inputs
- an API that publishes 5-minute network pricing and operating envelope data to an aggregator on a day ahead and near real-time basis, and
- a basic billing engine to determine the differential between the underlying network tariff and the dynamic network tariff for each Agent's customers'.[59]

Citipower and Powercor are jointly implementing a network support services platform (using Piclo Flex's technology) to procure ADER for network-congested areas.[60] CitiPower and Powercor are currently offering funding for 20 projects, with a total capacity required of 289MW and a deferral value of $7.75m.[61]

Interestingly, 'network support services' are not defined in the National Electricity Rules. Instead, there is a definition of 'network support agreement' in the glossary as:

> 'An agreement under which a person agrees to provide one or more [Network Support and Control Ancillary Services] to a Network Service Provider, including network support services to improve network capability by providing a non-network alternative to a *network augmentation*.'[62]

In Western Australia, Western Power has selected five distribution feeders for an expression of interest (EOI) for non-network solutions, which closed on 7 October 2024.[63]

Harnessing DER to provide network support services is almost always cheaper than building infrastructure because it uses existing assets (paid for by consumers) with only software and occasionally hardware (such as HEMS and smart meters) to unlock their coordination. In addition, owners of DER can be paid for providing these network support services, increasing their return on investment and reducing all consumer bills. This could reallocate revenue from distribution networks to DER owners.

Back in 2017, ENA and CSIRO's Electricity Network Transformation Roadmap forecast $16 billion in avoided network infrastructure investment by 2050 as a result of orchestration of DER to provide network services. This modelling also forecast distribution networks would be paying DER owners more than $2.5 billion per annum for grid support services by 2050.[64]

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[54] UTS Institute for Sustainable Futures (October 2019), Networks Renewed. Accessed 29 January 2025.
[55] CONSORT Bruny Island Battery Trial (2019), CONSORT (Bruny Island Battery Trial). Accessed 29 January 2025. Note: CONSORT was a collaboration between Australian National University, University of Sydney, University of Tasmania, TasNetworks and Reposit Power.
[56] ARENA (September 2022), DEIP DER Market Integration Trials Summary Report 1.0. Accessed 29 January 2025.
[57] Energy Security Board (12 February 2024), Consumer energy resources and the transformation of the NEM: Critical priorities to support transformation: a call to action [PDF]. Accessed 29 January 2025.
[58] Western Power (n.d.), Flexibility Services Pilot. Accessed 29 January 2025.
[59] Ausgrid (December 2023), Distribution and Transmission Annual Planning Report [PDF]. Accessed 29 January 2025.
[60] Citipower/Powercor (n.d.), Non-network opportunities. Accessed 29 January 2025.
[61] Piclo (n.d.). Citipower and Powercor. Accessed 29 January 2025.
[62] AEMC (2024), National Electricity Rules – Glossary. Accessed 29 January 2025.
[63] AEMO (n.d.), Expressions of Interest and Tender for NCESS – Reliability Services 2025-27 (WA). Accessed 29 January 2025.
[64] CSIRO and Energy Networks Australia (April 2017). Electricity network transformation roadmap: final report [PDF]. Accessed 29 January 2025.

ENA recently released a report with L.E.K. Consulting suggesting consumers could collectively avoid $7 billion in overall system costs in 2030 alone through more effective use of distribution networks, specifically:

- ‘7GW of additional “community generation” by 2030
- 5GW of additional Rooftop Solar by 2030
- 5GW of additional distribution-connected battery storage by 2030
- 1 million more EVs on the road by 2030
- coordination of consumer energy resources.’[65]

A report by the author identified 10 reasons why the existing economic regulation of distribution networks does not support the use of aggregated DER to provide network support services. The report recommends a fundamental review of the regulation by the Productivity Commission to address these issues.[66]

Conclusion: the speed of the revolution in distribution depends on engineers

The smart integration of DER into distribution networks could result in cheaper, faster decarbonisation.[67] This depends on innovative engineers both developing the technical solutions and engaging with policymakers and regulators to ensure they understand the opportunities and remove barriers in a timely fashion. The technical limitations on the integration of DER are not what is currently holding back the decentralisation, digitisation and decarbonisation of the energy system. It is the conservative mindset of those steeped in traditional ways of managing distribution grids, writing electricity rules, regulating distribution networks and operating the electricity market.

William Samuelson at Boston University and Richard Zeckhauser at Harvard jointly published the seminal paper on status quo bias in behavioural economics in 1988.[68] They showed that in a series of decision-making experiments, people disproportionally stuck with the status quo, with the familiar and standard ways they knew. Samuelson and Zeckhauser noted status quo bias is pervasive and is a natural repercussion of many well-known psychological traits.

Status quo bias is likely to be further enhanced by forms of professional training, institutional practices and cultures, for example, where engineering is taught as a highly procedural, reductionist, risk-averse discipline. Transmission engineering needs to be risk-averse given the risks to human life of high voltages and the financial risk of infrastructure that is commonly valued at hundreds of millions or billions of dollars. Market operators are typically dominated by personnel trained in transmission engineering, once described to the author as the ‘fighter pilots’ of the energy sector. Such technical prowess and responsibility may lead to an institutional ‘Top Gun’ culture of ego and control.

For the revolution in distribution, we need to recognise status quo bias and be less concerned with how the system has operated in the past and be more like maverick scientist Emmett ‘Doc’ Brown in *Back to the Future*: agile, innovative and harnessing lightning to change history.

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[65] Energy Networks Australia (August 2024), The time is now: Getting smarter with the grid. Accessed 29 January 2025.
[66] Kuiper G (31 May 2024), Reforming the economic regulation of distribution networks. IEEFA. Accessed 29 January 2025.
[67] Kuiper G (1 June 2022), Cheaper, faster decarbonisation: What State governments can do to support distributed energy resources. IEEFA. Accessed 29 January 2025.
[68] Samuelson W and Zeckhauser R (1988), Status quo bias in decision making. *Journal of Risk and Uncertainty*, volume 1, p. 7–59.

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About the Author

***Dr Gabrielle Kuiper** is an energy, sustainability and climate change professional with over 20 years' experience in the corporate world, government and non-government organisations and academia. Dr. Kuiper has held senior executive or senior advisory energy-related positions at the Energy Security Board, in the Office of the Australian Prime Minister, at the Public Interest Advocacy Centre (PIAC), and in the NSW Government. Dr. Kuiper currently works in Australia and internationally on policy and regulation to support distributed energy resources (DER) - rooftop solar, electric vehicles, smart appliances, etc. She is a guest contributor with the Institute for Energy Economics and Financial Analysis (IEEFA) and sits on four DER-related research and industry advisory bodies.*

Appendix

Taxonomy of Distributed Energy Resources (DER)

Note that while in general use, DER is treated as synonymous with renewable or zero-carbon energy, this is not necessarily the case, as small diesel generators, for example, also qualify as DER and batteries may be charged with coal-based grid supply. If distributed generation is solar and this – or decarbonised grid supply – is used to charge batteries, then DER uptake can speed up decarbonisation.

Aggregated DER (ADER) or a virtual power plant (VPP) is a network of DER – such as rooftop solar and battery systems, EVs and smart appliances – working together as a single power plant, aggregated via software to participate in the electricity system. The DER are plugged into the grid and, with an external or embedded hardware controller and sophisticated software, this supply and/or demand response can contribute to one or more markets.

Type/Connection	Generation Electricity generated at or close to the site of use	Storage Capturing energy locally produced at one time in chemical, thermal or other forms for use at a later time	Flexible load Appliances or machines which can have their time of use altered passively (e.g. through a timer) or dynamically in response to local or external signals
Behind-the-meter (BTM)	• Rooftop solar • Ground-mounted solar • Floating solar – flotovoltaics • Canopy solar • Rooftop wind • Microturbines (small diesel/biodiesel/gas generators) • Combustion turbines (medium diesel/biodiesel/gas generators) • Cogeneration/trigeneration/ combined heat and power • Fuel cells (hydrogen/gas/propane, etc)	• Electric hot water systems • Chilled water storage • Battery storage • EVs • EV charging stations with bidirectional charging • Hydrogen vehicles	• Household load with passive or active management • Commercial load with passive or active management • Industrial load with passive or active management • EV charging stations with unidirectional charging
Front-of-the-meter (FTM) low-voltage (LV) distribution connected	• Rooftop solar • Ground-mounted solar • Floating solar • Rooftop wind • Microturbines (small diesel/biodiesel/gas generators) • Combustion turbines (medium diesel/biodiesel/gas generators) • Cogeneration/trigeneration/ combined heat and power • Fuel cells (hydrogen/gas/propane etc.)	• Battery storage • EV charging stations with bidirectional charging • District cooling • District heating	• Commercial load with passive or active management • Industrial load with passive or active management • EV charging stations with unidirectional charging • District cooling • District heating