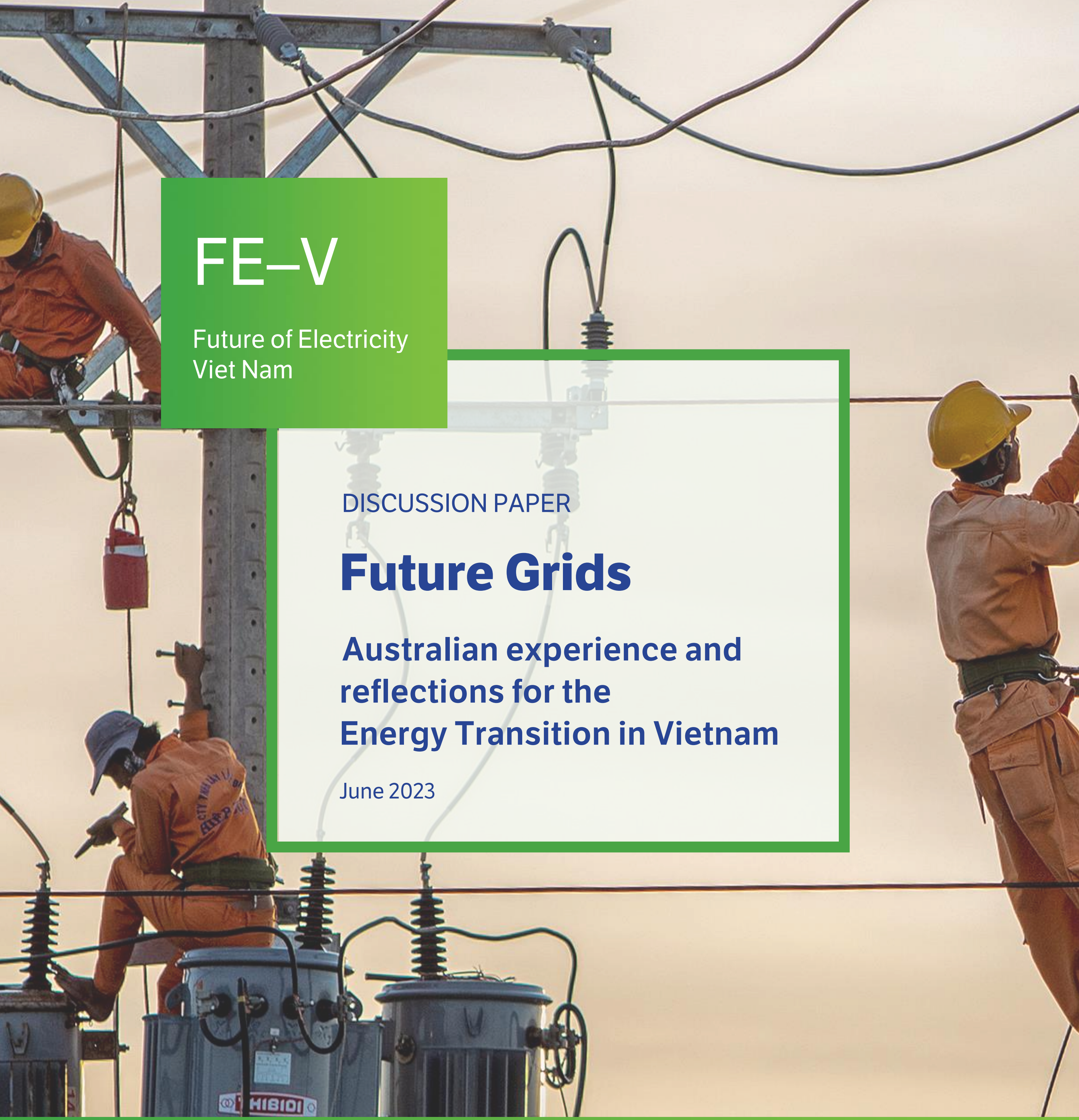

FE–V

Future of Electricity
Viet Nam

DISCUSSION PAPER

# Future Grids

## Australian experience and reflections for the Energy Transition in Vietnam

June 2023

Australian Government

## About Future of Electricity Vietnam (FE-V)

Australia and Vietnam are neighbours and peers, facing the same regional challenges and sharing the same aspirations for sustainable, secure, and fair electricity services as the basis of prosperity and economic growth. Our power sectors: share many legacy issues on how energy is generated and transmitted; are blessed with high renewable energy (RE) potential and some of the fastest rates of RE deployment in the world; and are undertaking (or have recently undertaken) major structural reforms to the markets, governance arrangements and infrastructure that underpin the sector in order to take advantage of the opportunity presented by a sustainable energy transition.

Future of Electricity Vietnam (FE-V) is a science-to-policy program made up of policy dialogues aimed at leveraging the Australian experience in energy transition to support Vietnam in exploring practical and feasible interventions for a decarbonised, reliable and affordable power system.

Recognising 50 years of diplomatic relations between Australia and Vietnam, FE-V is an initiative of the Australian Embassy in Hanoi bringing Australian and Vietnamese experts together to share experiences and to co-develop knowledge products of prioritised topics relating to 5 main dimensions of the power sector (generation, fuels, consumption, grid and market) with the Central Economic Commission of the Communist Party of Vietnam (CEC), a strategic dialogue partner. The FE-V initiative is divided into two phases. The first phase focuses on providing high-level inputs for an energy transition strategy, including a review of the 3-year implementation of Resolution 55 which CEC is carrying out.

FE-V is delivered by Australia's Partnerships for Infrastructure (P4I) and the Australia - Mekong Partnership for Environmental Resources & Energy Systems (AMPERES) together with the Australian National University (ANU) and Commonwealth Scientific Industrial Research Organisation (CSIRO). P4I is an Australian Government initiative partnering with Southeast Asia to drive sustainable, inclusive, and resilient growth through quality infrastructure. Led by the Australian Department of Foreign Affairs and Trade, P4I is implemented by EY, Adam Smith International, The Asia Foundation and Ninti One.

## Authors

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Photo: Workers fix electric cables in Bac Lieu Province. Photo by VnExpress/Nguyet Nhi.

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## Disclaimer

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# List of Figures

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# List of Abbreviations

| Abbreviations | Full name |
|---|---|
| AEMO | Australian Energy Market Operator |
| CROF | Control Room of the Future |
| CROF | Control Room of the Future |
| DMIS | Demand Management Incentive Scheme |
| DMIAM | Demand Management Innovation Allowance Mechanism |
| DER | Distributed Energy Resources |
| EPRI | Electric Power Research Institute |
| EF | Engineering Framework |
| FFR | Fast Frequency Response |
| FIT | Feed-in-Tariffs |
| FCAS | Frequency Control and Ancillary Services |
| G-PST | Global Power System Transformation |
| GHG | Greenhouse Gas |
| GFMI | Grid-forming Inverters |
| RTPV | Grid-Interactive Rooftop Solar PV Plants |
| GDP | Gross Domestic Product |
| HVDC | High Voltage Direct Current |
| HCMC | Ho Chi Minh City |
| IBR | Inverter-based Resources |
| MOIT | Ministry of Industry and Trade |
| NEM | National Electricity Market |
| NLDC | National Load Dispatch Center |
| NPT | National Power Transmission Corporation |
| NSW | New South Wales |
| PV | Photovoltaic |
| PDP | Power Development Plan |
| PPA | Power Purchase Agreements |
| PSA | Power Systems Architecture |
| PSH | Pumped storage hydropower |
| RoR | Rate of Return |
| RAB | Regulated Asset Base |
| RIT-T | Regulatory Investment Test for Transmission |
| RERT | Reliability and Emergency Reserve Trader |
| RE | Renewable Energy |
| REDS | Renewable Energy Development Strategy |

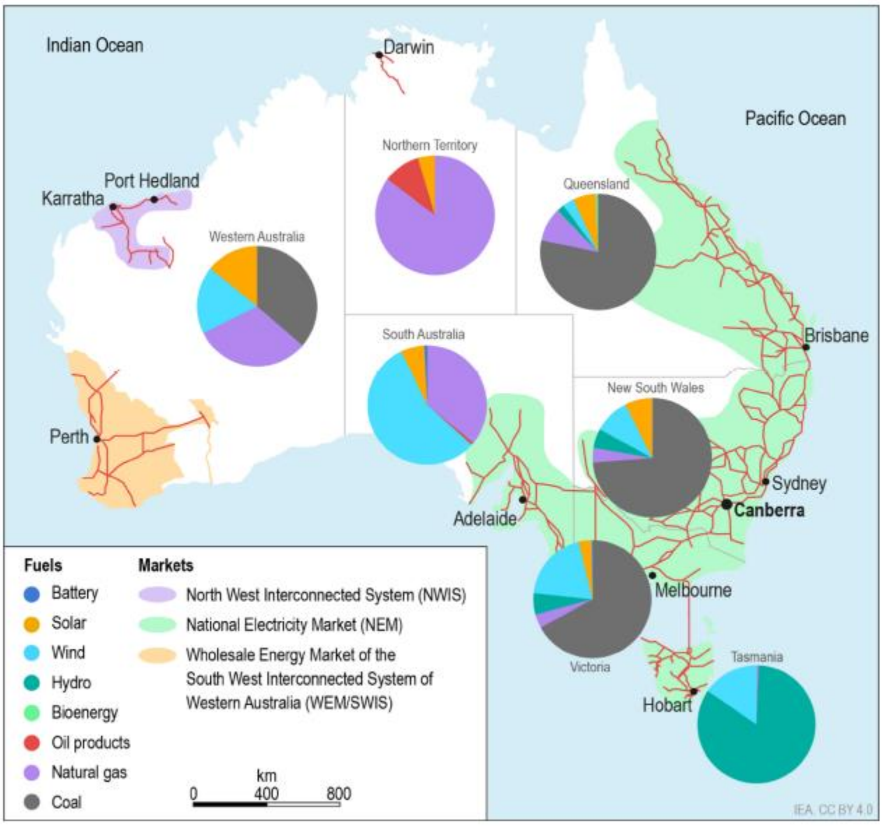
| | |
|---|---|
| REZ | Renewable Energy Zones |
| RTS | Rooftop Solar |
| SoEs | State-owned Enterprises |
| SRAS | System Restart Ancillary Services |
| TWh | Terawatt hours |
| TNSPs | Transmission Network Service Providers |
| VRE | Variable Renewable Energy |
| EVN | Vietnam Electricity |
| WEM | Wholesale Electricity Market |

# A. Thematic Setting

There are two major electricity markets in Australia – the National Electricity Market (NEM) on the east coast and the Wholesale Electricity Market (WEM) in Western Australia (Figure 1). The NEM is both a physical power system and a wholesale electricity market through which generators and retailers trade electricity. There are more than 500 registered participants, including generators, network service providers, (large) customers, and traders, in the NEM supplying over 200 terawatt hours (TWh) of electricity a year.[1] The WEM has over 70 participating generators and supplies approximately 20 TWh per year.[2] The NEM and WEM are governed by different regulatory bodies, but the Australian Energy Market Operator (AEMO) plays a role in the operations of both.

**Figure 1 |** Extent of NEM and WEM transmission networks in Australia.

*Source: International Energy Agency Australia 2023 Energy Policy Review, Figure 7.3*



## A1 - Overview: Decarbonisation and increasing renewables

In 2000 more than 92% of electricity generation in Australia was supplied by fossil fuels – black and brown coal, gas, and a small proportion of oil – and the majority of renewable energy was hydroelectricity. From 2008, various Australian states offered feed-in-tariffs for rooftop solar PV, resulting in significant growth in installation numbers. By 2021 less than 71% of

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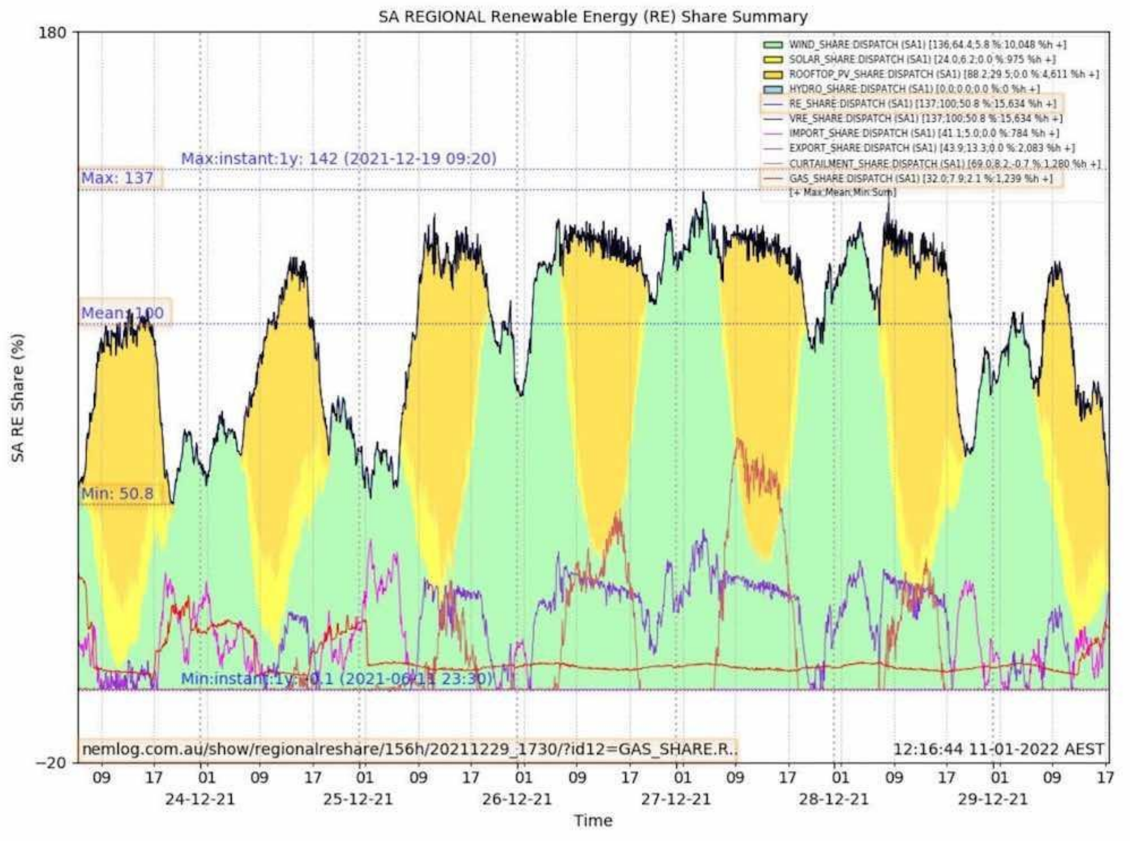
[1] AEMO (2021), National Electricity Market fact sheet [PDF], accessed 19 April 2023.

[2] AEMO (2022), Fact sheet: How the wholesale electricity market works, accessed 19 April 2023

generation was fossil fuels[3], with hydroelectricity representing less than a third of the remaining renewable energy generation, the rest was made up by wind and solar generation. Under the current Federal Government, there is a renewable generation target of 82% by 2030[4] while end-user electricity demand is expected to increase more than 20%, with the increase in renewable energy generation made up entirely by wind and solar PV.[5]

**Figure 2 |** Renewable energy electricity share in South Australia, December 2021.

*Source: NEMlog[6]*



Although over a full year the average contribution to total NEM demand of renewables in 2022 was 36%,[7] the instantaneous renewable generation record was more than double that with 64% in September 2022. 'In a world first for a grid of its size, South Australia recorded more than 10 consecutive days when average production of wind and solar accounted for 100% of the state's demand.'[8] (see Figure 2) As the costs of wind and solar generation are expected to continue to decrease, projections for the future of Australian electricity generation show a continuation of the trend of declining fossil fuel contribution.

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[3] Department of Climate Change, the Environment, Energy and Water (DCCEEW) (2023) Australian Energy Statistics, Table O Electricity generation by fuel type 2020-21 and 2021, accessed 18 April 2023.

[4] Clean Energy Regulator (CER)(2023) State of Renewables, accessed 18 April 2023.

[5] D Clarke and P Graham (2021), Australian electricity transitions 1900 to 2050 (Figure 2-1), CSIRO, accessed 19 April 2023.

[6] Vorrath, S. (2022), South Australia sets smashing new renewables record in final days of 2021, accessed 4 May 2023

[7] Saddler, H (2023) Australian Energy Emissions Monitor, The Australian National University website, accessed 18 April 2023.

[8] Clean Energy Regulator (CER) (2023) State of Total Renewables, CER website accessed on April 18, 2023.

**Box 1 |** Notable Australian climate policy milestones in the electricity sector

Notable Australian climate policy milestones in the electricity sector include the following:

2001: implementation of the Mandatory Renewable Energy Target scheme, which mandated that by 2010 electricity retailers and other large buyers source an additional 2% of electricity from renewable sources.[9] The target was met 4 years ahead of schedule.

2007: the National Greenhouse and Energy Reporting scheme[10] is established, creating a national framework for reporting greenhouse gas emissions, energy production, and energy consumption.

2009: the Renewable Energy (Electricity) Amendment Bill[11] set the Renewable Energy Target to have an additional 20% of electricity generated from renewable sources by 2020 (compared to 1997 levels).

2011: the passage of the Clean Energy Act 2011[12] legislated an Australian emissions trading scheme and created the Climate Change Authority advisory board and Clean Energy Finance Corporation. The Clean Energy Act was repealed in 2013.

2015: the renewable energy target is adjusted to 23.5% (33,000 gigawatt hours) of electricity generation by 2020. Later that year, the government announced a target of net zero emissions by 2100. The reduced target was met a year early in 2019[13]

2017: the Independent Review into the Future Security of the National Electricity Market (the Finkel Review) made 50 recommendations, 49 of which were adopted[14]

2020: the Federal Government announced a target of net zero emissions by 2100.

2022: the Climate Change Bill 2022[15] directs a 45% reduction in greenhouse gases (from 2005 levels) by 2030 and net zero by 2050.

## A2 - Evolution of the theme: integration of intermittent and inverter-based generation

The significant decrease in the relative proportion of fossil fuel and hydro-electric generation compared to wind and solar generation present some new technical challenges for the generation network. This is because wind and solar generation is coupled to the network somewhat differently to fossil fuel generation. Coal and gas generation is implemented electromechanically via the rotation of turbines at the speed of the network electrical power frequency, (50Hz in both Australian and Vietnam). Gas can power rotating turbines directly, whereas other electromechanical generators are driven by steam turbines heated by boilers burning coal or gas. These generators are called synchronous machines, because they rotate in synchronism with the power

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[9] Australian Government (2016), *Federal Register of Legislation: Renewable Energy (Electricity) Act 2000*, accessed 19 April 2023.
[10] Australian Government (2007), *National Greenhouse and Energy Reporting Act*, accessed 19 April 2023.
[11] Parliament of Australia (2009), *Renewable Energy (Electricity) Amendment Bill 2009*, accessed 19 April 2023.
[12] Australian Government (2011), *Clean Energy Act 2011*, 2011, accessed 19 April 2023.
[13] CER (2019) *2020 Large-scale Renewable Energy Target capacity achieved*, accessed 18 April 2023.
[14] Finkel et al. (2017) *Independent Review into the Future Security of the National Electricity Market*, DCCEEW website, accessed 26 April 2023.
[15] Parliament of Australia (2022), *Climate Change Bill 2022*, accessed 19 April 2023.

system (and each other). Hydroelectricity can also be generated by synchronous rotation.

In contrast, wind and solar generation (and batteries) are coupled to the network via power electronics devices (inverters), which are required to deliver power to synchronise with the rest of the network. The frequency of power delivered by these inverter-based resources (IBR) is regulated by controllers associated with each inverter. Electromechanical synchronous generation devices behave somewhat differently to inverter-based generators in terms of how they respond to slight, inevitable, mismatches between electricity demand and electricity generated, creating technical challenges in maintain a stable balance, since traditional processes and standards are not well suited to the newer technology.

Further challenges with integrating increasing quantities of wind and solar generation into the power system arise because the energy resources are intermittent, or variable. Fossil fuel generation is dispatchable, that is it can be delivered at will, because the fuel source, which represents (chemical) energy storage, is always available. As an increasing proportion of generation capacity relies on an intermittently available energy source, it becomes increasingly challenging to ensure that there will always be sufficient electricity supply to meet demand.

## A3 - Importance of theme to the Australian electricity services industry

The shift to renewable electricity generation is key component of Australia's decarbonisation strategy, given that the power sector is one of the highest emitting sectors of the Australian economy16. As electricity can be used as a substitute for other fuels such as coal, gas and oil, low emissions electricity provides further options for reducing the reliance on high emissions industrial and transport process, via electrification.

It follows that solving the technical challenges of integrating inverter-based generation supplied by intermittent energy resources is crucial to the decarbonisation of the Australian economy. These challenges apply alike to small-scale rooftop PV and large-scale renewable generation farms.

## A4 - List of key issues: grid stability and energy reliability

The key technical grid issues for the future of electrical power systems, as the change in dominant generation technology shifts from synchronous generation to inverter-based generation, and from dispatchable to intermittent energy supplies, are grid stability and energy reliability. Grid stability amounts to the ability of the electrical power system to maintain a balance between total generation and load on short term time scales of the order of minutes to fractions of a second. These must be kept in balance within quite tight tolerance limits to prevent synchronous generators from disconnecting, which

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[16] Department of Climate Change, the Environment, Energy and Water (DCCEEW) (2022), *Quarterly Update of Australia's National Greenhouse Gas Inventory: March 2022*, *[PDF]*, *accessed* 27 April 2023.

could result in a chain reaction and system blackout. Energy reliability is dependent on grid stability, but further also always requires an adequate quantity of energy resources, and capacity of the transmission network, to supply total demand.

Grid stability and energy reliability are affected by several factors, each of which will be discussed separately in the remainder of this discussion paper. They are:

1. Impacts of power technology devices (such as generators and batteries) on grid stability, energy reliability and restoration
2. Power system operator capability to maintain grid stability and energy reliability.
3. The capacity of transmission and distributions networks to meet energy demand with high reliability, irrespective of the location and fluctuation of energy sources.
4. Coordination of distribution scale power technology devices for energy reliability.

There are some overlaps among these factors, so that some issues and potential solutions will not fit neatly within a single topic above. There are also numerous interactions, primarily trade-offs, so that many solutions to improve capability in one of the above areas will typically relieve some pressure to improve capability in the others.

## A5 - Relevance to Vietnam

During the 1990s and early 2000s Vietnam's power sector was focussed on expanding energy access as the predominant energy security concern. This agenda saw access rise from less than 15% in 1994 to greater than 98% in 2017. The success of this electricity access agenda coincided with rapid growth and industrialisation of the Vietnamese economy – together these factors produced a rapid rise in electricity demand and saw grid stability and energy reliability emerge as predominant energy security concerns for the power grid:

- Grid stability during this period was of limited concern, as the majority of the electricity was generated by synchronous machines (hydro and coal), which inherently provide fast-time scale balancing inertia, and may be equipped with automatic generation controls.
- Energy reliability was framed by a geographical challenge – most of the generation capacity (hydro and coal) was in the north of Vietnam, whilst the load was dominated by industrial provinces of the south (HCMC, Dong Nai). Balancing supply and demand therefore required build out of high voltage transmission lines and associated infrastructure over large distances.
- The reliability of energy supply during this period was also significantly challenged by electricity demand which was growing on average 1.8 times faster than GDP and required an unprecedented build out of new generation capacity. Keeping up with demand was and remains a major challenge for the power sector. Significant delays in the build out of coal power stations during 2010 – 2018 and the fact that there remains no

untapped capacity for large hydropower within Vietnam has tied energy reliability to a need for new types of generation.

During the past five years, Vietnam has realized the importance of developing renewable energy (wind and solar) to meeting its increasing demand while at the same time addressing the environment issue (i.e., GHG emission). Government policies that address renewable energy development were set forth with the issue of Renewable Energy Development Strategy (REDS) under Decision 2068/QĐ-TTg dated 25 November 2015, where renewable energy targets were set at 38% of total electric generation in 2020, 35% in 2025, 32% in 2030, 38% in 2040 and about 43% in 2050. This is equivalent to an increase from 58 billion kWh in 2015 to about 186 billion kWh in 2030 and 452 billion kWh in 2050.

Decision 428/QĐ-TTg, dated 18 March 2016, better known as the revised Power Development Plan VII (PDP7-revised), set out specific targets for each type of renewable energy. For solar energy, the target was 850 MW by 2020, increasing to 12000 MW by 2030. For wind energy, the target was 800 MW by 2020, increasing to 2000 MW by 2030.

By 2021, Vietnam overachieved the PDP7 target for 2030 with 16,773 MW of solar PV and 4161 MW of wind power. This substantial and rapid development has created several problems.

- Grid congestion due to low power demand in the areas where solar PV and wind farms are located, leading to RE curtailment particularly during the pandemic periods.
- Change in the power flow: i.) from the Centre and the South to the North as opposed to traditional North-south direction (due to location of solar PV and wind power in the centre and in the south) and ii.) From low voltage to higher voltages due to connection of RE to low voltage grid with capacity higher than the local demand.
- Grid stability due voltage and frequency fluctuation and harmonics resonance of renewable energies.

The 2023 Power Development plan 8 forecasts, by 2030, 21880MW onshore wind capacity, 6000MW offshore capacity, and 12836 MW solar, excluding existing rooftop solar, which was more than 7800MW in 2021[17]

## A6 - Recommendations to Vietnam

Considering that more and more wind and solar will be developed and will dominate the system, Vietnam could consider the followings:

- Identify renewable energy zones to guide the development of transmission grid including the common grid infrastructure.
- Take a systematic approach to develop the backbone network (considering the necessity of higher voltage AC network or high voltage DC network)
- Enable non-state actors to make investment and operation of specific transmission lines.
- Develop battery storage systems to enhance power quality.

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[17] EREA & DEA (2022), *Viet Nam Energy Outlook Report 2021* , p53

- Develop pumped hydro long term energy storage to balance fluctuations in wind and solar resource availability (consistent with PDP8 projections of requirements for 30650-45550 MW power storage by 2050)
- Consider the potential for battery electric vehicles to provide flexible demand, or contribute to energy storage to supply consumers at times of high electricity demand (vehicle to home or vehicle to grid)
- Enhance visibility of RTS for the system operator
- Consider the development of virtual power plants to take advantage of existing RTS particularly when they are equipped with battery storage systems to provide ancillary services.
- Consider the potential of allowing limited export of rooftop solar to the grid within the distribution network, which could relieve the requirement for investment in centralised generation capacity, new transmission, and distribution network, especially if combined with distributed battery storage systems (both utility-scale and behind-the-meter customer scale) to supply during times of peak demand. While PDP8 encourages rooftop power for self-consumption, allowing grid export up to the technical limits of the distribution network is part of a least cost electricity supply solution.

# B. Issues exploration

## Issue 1 - Impacts of Power Technology Devices (such as generators and batteries) on grid stability, energy reliability, and restoration

### B1 - Problem Context (What): Changing mix of synchronous and inverter-based resources

The capital costs of renewable energy, such as onshore and offshore wind, and especially solar PV, have decreased significantly over the past decade[18], and is expected to continue to do so[19]. Decarbonisation goals, such as those for Australia mentioned above, provide additional incentives to increase the proportion of wind and solar powered electricity generation compared to fossil fuel generation such as coal and gas, which are more greenhouse emissions intensive. In 2021, the proportion of Australian electricity generated from wind and solar was 22%[20], an increase from 2001 of less than 1%, and it is projected to continue to increase for the foreseeable future[21], as coal and gas generation capacity is retired over the coming decades.

The changing mix of electricity generation capacity means that maintaining grid stability, energy reliability, and restoring electricity supply after a black out, must all be managed differently. As mentioned above energy reliability is more challenging to manage because wind and solar renewable energy is variable rather than dispatchable, and grid stability must be managed differently because wind and solar power is inverter-based (asynchronous) rather than synchronous. Battery storage, which represents one possible technological solution to helping to manage energy reliability, by smoothing out generation variability, is connected to the transmission network by power inverters, and so is also an inverter-based (electrical power) resource[22].

### B2 - Strategic setting (Why): generator disconnection risk

#### Inertia and primary frequency response

Synchronous machines: such as steam turbine electrical generators, gas turbine generators, synchronous condensers, and flywheels; store energy as rotational inertia. Their inherent physical dynamics are such that they increase or decrease speed to compensate for any minor fluctuations in power system load on the time scales of

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[18] IRENA (2021), Renewable Power Generation: Costs in 2021, Table H1, [PDF], Accessed 27 April 2023

[19] CSIRO (2022), GenCost 2021-22 – Final Report, [PDF], accessed 27 April 2023

[20] Department of Climate Change, the Environment, Energy and Water (DCCEEW) (2021), Renewables, Online Website, accessed 27 April 2023.

[21] AEMO (2022), 2022 Integrated System Plan, [PDF], accessed 27 April 2023.

[22] Hodge, B-M S. et al, J 2020, Addressing technical challenges in 100% variable inverter-based renewable energy power systems, viewed 27 April 2023.

seconds and faster, so that balance between generation and load is maintained.

Inverter-based generators do not necessarily have the stored energy (physical capability) to provide additional power as required to maintain that instantaneous system-wide power balance. Furthermore, they do not necessarily have the designed response (operational capability, controllability) to compensate for power system imbalances as signalled through frequency changes.

If there is insufficient inertia-like stabilising behaviour capacity in the power system, the frequency of the electrical power system could deviate too fast or too far. This may be outside the safe technical limits of synchronous machines that are connected. They will disconnect to prevent being physically damaged, which could result in further, unacceptable, supply imbalance. This risks a chain reaction of disconnecting equipment and a system blackout.

> *In 2022, owing to changes in the behaviour of synchronous generators and increasing quantities of inverter-based generation, inertia shortfall forecasts were declared in two regions of the NEM, Queensland and Victoria, adding to known inertia shortfalls in South Australia and Tasmania[23].*

## Secondary frequency response and emergency reserves

System inertia alone allows the power system to accommodate a temporary imbalance between generation and load for only a short period of time (several seconds). To match fluctuations in electrical load over longer time frames, such as minutes to hours, the generator fleet in aggregate must increase or decrease its output.

This requires the maintenance of both ‘head room’ (physical capability) and dispatch authority (operational capability, controllability). Head room is the difference between a given generator’s existing output and maximum technically possible output. It is the physical capability allowing the generator output to increase to match an increase in power demand. There is also required some mechanism to ensure that, given the physical capacity to change generation output, a generator actually does so. This can be via an automatic control system; or via instructions from the power system operator for each generator to increase or decrease output, a decision that may or may not be the outcome of a market bidding and clearing process.

Similarly, in the event of an unexpected loss of a generator or transmission link, it may be necessary to quickly dispatch an emergency reserve generator to make up deficiencies in aggregate supply.

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[23] AEMO (2022), *2022 Inertia Report: A Report for the National Electricity Market*, [PDF], Accessed 27 April 2023.

Traditional synchronous generation fuelled by coal, gas, oil, or hydro-electric potential energy, is typically dispatchable, meaning that its output can be reliably varied up or down according to need, or brought online to replace a significant loss of supply in an emergency. In contrast, renewable energy resources are not always dispatchable, but only available intermittently. This means that, as more of the generation capacity of the total fleet becomes reliant on variable renewable resources, alternative approaches are required to reliably maintain sufficient standby (flexible) reserve capacity for both regularly expected fluctuations in load, and for emergencies. Maintaining head room is relatively low cost for synchronous generation, as it saves on fuel use. It is straightforward to maintain head room with "overbuilding" of variable renewable energy resources, but this represents leads to curtailment with no savings in fuel costs.

## System strength changes

System strength at a specific network location is the capability of the power system to provide a strong voltage signal, particularly under fault conditions[24]. If the system strength at a particular network location is deficient, a fault or other disturbances could result in a loss of satisfactory voltage signal, which could make it difficult for some generators to remain synchronised to the power system.

A synchronous machine typically has the capability to provide more system strength than a similarly (power output) rated inverter-based generator. In some cases, the connection of an inverter-based generator can reduce the system strength at some locations in the transmission network or increase system strength requirements near its point of connection. It follows that as a greater proportion of the generator fleet is inverter-based rather than synchronous, the system strength that was previously available from synchronous generators may be required to be provided by other means.

> *Accelerated uptake of inverter-based resources (IBR) and withdrawal of synchronous generators is creating a need for new system strength solutions…*
>
> *Australia is currently installing utility-scale IBR faster than at any time in history, and the trend is projected to increase. … coal-fired generators are continuing to bring forward their withdrawal from the market.*
>
> *As system strength has traditionally been provided by synchronous generators, and IBR generally require additional remediation to prevent adverse system strength impacts on the power system, there is an urgent need to plan for the provision of system strength services to facilitate this once-in-a-generation transformation of the power system.*[25]

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[24] AEMO (2020) *System strength in the NEM explained* [PDF], AEMO website, accessed 19 April 2023.
[25] AEMO (2022) *2022 System strength report* [PDF], AEMO website, accessed 24 April 2023.

### Black start procedure changes

Restoring a power system after a blackout is a co-ordinated, step-by-step procedure involving the reconnection of individual generators one by one. To be restored from a non-operating condition, many larger generators require electrical power to be available to both provide start-up energy and a reliable oscillating voltage signal which is required to regulate their speed of rotation.

Synchronous generators typically have the capability to reliably provide start-up power and a strong voltage signal so that other larger generators can be restored from a non-operating condition. There are well understood procedures for restarting a fleet of synchronous generators.

However, inverter-based generators are typically not able to provide as much energy as similarly rated synchronous generators to provide start-up energy for the operation of other generators to be restored. Furthermore, depending on their control design, many inverter-based generators are less capable of providing the strong, stable, oscillating voltage signal that is required to permit synchronisation. Better understanding is required of the ability of inverter-based resources to contribute to system black start, so that system restart can be reliably achieved notwithstanding the changing mix of the generation fleet.

> *Over time, the number of large synchronous generating units with SRAS capability is likely to reduce as these generators are retired. The current fleet of IBR cannot provide SRAS capability, so new resources will be required to ensure restoration standards can continue to be met into the future*[26]*.*

## B3 - Solutions (How): Device technology improvements for grid stability, energy reliability, and restoration

### Grid services from inverter-based resources

To address the emerging issues created by transitioning to a greater number of inverter-based resources (IBR), alternative inverter control methods such as those created by grid-forming inverters (GFMI) are necessary to help achieve a secure, stable, and reliable grid. This includes utility scale battery storage, which was expected to reach 1.1 GW capacity in Australia in 2022[27]. Development of these methods requires exploration of control strategies, protection schemes, and modelling approaches for IBR-dominated grids. To this end, Australia is investigating possible enhancements to the

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[26] AEMO (2021), *Application of Advanced Grid-scale Inverters in the NEM*, [PDF] accessed 27 April 2023.

[27] Australian Financial Review, *Australia's battery capacity set to double within months*, AFR Website, Accessed 27 April 2023.

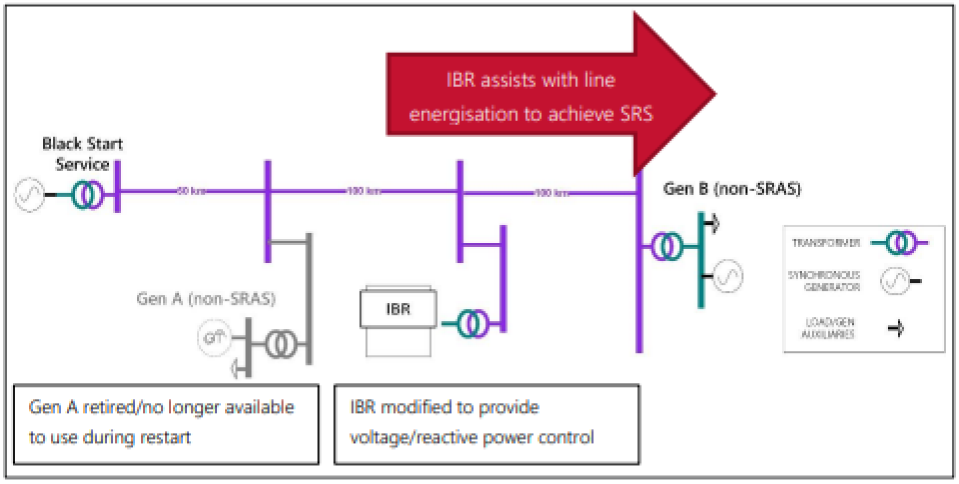
performance of inverter-based resources, as part of a Global Power System Transformation (G-PST) Consortium in the following areas[28]:

- frequency stability - Defining IBR frequency response requirements for future grids, especially for contingencies
- voltage stability - Investigating reactive capability and voltage control requirements of IBR, especially interactions automatic voltage regulation,
- interaction mitigation and oscillation damping - Identifying the source, and resolving, adverse interaction among aggregated IBRs, especially oscillations in IBR-dominated grids
- protection and reliability - Proposing mitigation methods, such as enhancing IBR response, for adverse impacts of IBRs on control and protection in the grid,
- advanced IBR control methods –especially for grid forming inverters and including "virtual" inertia.

## Grid restoration with inverter-based resources

**Figure 3 |** Example restart with Inverter Based Resources as Restoration support

*Source: Figure 2 of AEMO (2020), SRAS guideline system restart ancillary services*



Australia's traditional black-starting resources, predominantly coal and gas-fired turbines, are aging, face retirement in the coming decades and will largely be replaced by DER. In an electricity grid with increased amounts of DER and therefore high levels of IBR, new systems and procedures must be implemented to ensure there are effective processes and capability in place should the need for black-start services arise. Australia's contribution to G-PST Consortium[29] is investigating:

- IBR as restoration support in system restart services

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[28] CSIRO (2023), *Australia's Global Power System Transformation (G-PST) Research Roadmap, CSIRO Website, Accessed* 27 April 2023.

[29] Global Power System Transformation (G-PST) Consortium website, accessed 26 April 2023.

- Assessing the impact of various system restoration methodologies on network controls and protection systems
- Establishing new and expanding existing tools and techniques to develop wide-area simulation models to test and evaluate the existing restart processes
- Developing technical and regulatory requirements that include specific restoration requirements into long-term planning requirements
- Contemplating the end-to-end power system restoration that optimises the use of IBRs and manages the increasing amount of DER.

### Traditional solutions: automatic generator controls, synchronous condensers

Some existing technologies can ameliorate some of the consequences of increasing proportions of inverter-based generator supplying the electrical power system. Synchronous condensers and flywheels, for example, are a relatively low-cost replacement for rotational inertia, and can also provide a transmission network with additional system strength.

Frequency stability can be enhanced by ensuring that automatic generator controls, which help thermal generation plant to respond to frequency changes with changes to output, are appropriately tuned and active.

Open cycle gas and hydroelectric – including off-river pumped hydroelectric – generation are relatively low-cost options for providing flexible generation that can compensate for short term fluctuations and can also contribute to providing inertia (primary frequency) response and emergency reserves.

For energy reliability, demand response, where specific customers reduce (or perhaps even increase) their consumption to assist with balancing available supply, can also be incorporated into the suite of options. Demand response can also be included for contributing to emergency reserves.

## B4 - Reflection on Australian experience: Devices to maintain grid stability, energy reliability, and restoration

To date the Australian response to the prospects of declining inertia and flexible generation provided by synchronous generation has been a combination of traditional solutions and regulatory changes that permit a broader range of technologies to contribute.

For system strength and inertia:

- a 100 MW battery (80 minutes storage) was installed in 2017 at Hornsdale, South Australia, the battery was installed to provide stability to the South Australian electricity grid, facilitate “firming” of renewable energy and reduce the chance of loadshedding events. Expanded in 2020 (an added 50MW), the battery now has Tesla's "Virtual Machine" capabilities providing fast frequency response services[30] by virtually emulating mechanical inertia[31], much like "technology replaced cogs to produce the digital watch"[32]

- a 50 MW battery was installed in Jan 2022 at Wallgrove, NSW, undergoing "synthetic inertia" and other grid forming capability trials providing to grid frequency security to the wider Sydney region.[33] The battery employs the same Tesla "Virtual Machine" technology used in the Hornsdale battery but applies it directly to the city demand profile.

- synchronous condensers were installed in South Australia in 2021 to support system strength[34]
- the provision of primary frequency response by synchronous generators was made mandatory in 2021[35] Part of the wider "Frequency Control Plan", the rules stipulated all scheduled and semi-scheduled generators must automatically respond to small changes in frequency either side of 50Hz.

- the Victorian Big Battery Project was commissioned in December 2021. The 450MWh Battery Energy Storage Solution (BESS) stores enough energy to power over million Victorian homes for 30minutes. This provides black out protection through "firming" of cheap renewable energy prices.[36]

- in 2021, the suite of frequency support services (Frequency Control Ancillary Services), with previously existing markets at 300, 60, and 6 seconds, added new 'fast frequency response' markets at 1 second time scales.[37]

Performance standards for utility scale inverter-based resources have recently been tightened:

- The Australian Energy Market Operator developing a report on the potential contribution of inverter-based grid forming inverters to maintaining voltage stability[38]
- Rules implementing minimum requirements for the provision, by large scale inverter-based resources, of voltage-supporting reactive current during fault conditions[39]

- Further alterations of the "National Electricity Amendment" will commence 3rd June 2024. Alterations tighten operating/fault

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[30] Aurecon (n.d.), Projects Hornsdale Power Reserve, Australia, accessed 20 April 2023.
[31] TESLA (2023), *Tesla Energy Software*, accessed 5th May 2023
[32] Transgrid (2023), *Wallgrove Grid Battery*, accessed 1 May 2023
[33] Transgrid (2023), *Wallgrove Grid Battery*, accessed 1 May 2023
[34] ElectraNet (2021), *Strength, reliability boost to South Australia's electricity network*, accessed 20 April 2023.
[35] Australian Energy Market Commission (AEMC) (2020), *Mandatory primary frequency response*, accessed 20 April 2023.
[36] Victorian Big Battery, *Our Battery, accessed 2nd May 2023*
[37] AEMC (2021), *Fast frequency response market ancillary service*, accessed 20 April 2023.
[38] AEMO (2021), *Application of Advanced Grid-scale Inverters in the NEM*, [PDF] accessed 27 April 2023
[39] AEMC (2023), *National Electricity Amendment (Efficient Reactive Current Access Standards For Inverter based Resources) Rule 2023, [PDF], accessed* 27 April 2023

conditions, improving grid connectivity efficiency but conversely allows further flexibility for OEMs to design responses to complex fault patterns.

As Australia continues to adapt to a grid system dominated by inverter-based generation, further investigation is required to understand how it will affect the capability of the generators to balance supply and demand at all time scales, including under contingency and emergency events, and to restore generation operations in the event of a black system.[40,41]

Strides have been made in the last 10 years, with successful implementation of large-scale battery/virtual inertia technology in industry, in some cases providing half the state required inertia for SA. This progress is not insignificant, and can provide a pathway for other states, territories and countries to follow looking forward.

## B5 - Reflection on Vietnamese significance

Historically Vietnam's electricity mix was dominated by coal and hydropower which provided sufficient inertia for grid stability; while hydropower, oil and gas provided dispatchable generation capable of providing flexibility in response to variations in demand. However, since 2020 Feed-in-Tariffs for solar, roof-top solar and onshore wind have seen variable renewable energy connected to the Vietnamese grids at world-leading rates. In 2019 there was just 5.7 GW of solar, wind and RTS on the Vietnamese grid, by the end of 2021 7.8 GW of RTS, 8.9 GW of utility solar and 4.2 GW of onshore wind had been added into the system comprising 27 % of system installed capacity and 8 % of total generation[42]. The solar and wind tariffs were closed in December 2020 and November 2021 respectively, since then no additional VRE has been added to the VN system, in fact there are 84 solar and wind projects (so called 'transitional RE projects') which are already under development but did not meet the FIT commissioning deadline, which represents 4.7 GW of unutilised capacity waiting to connect to the grid.

The halt in the deployment of additional VRE capacity since the end of 2021 is in part due to grid congestion issues which are acute in south central Vietnam, but primarily due to the grid-wide stability and energy reliability issues which higher penetration VRE would induce and for which Vietnam's historical experience provides no solutions. These issues, therefore, are central barriers currently inhibiting higher penetration of renewables into the grid.

Reflecting on the Australian experience with these same issues, Vietnam's grid needs more zero carbon dispatchable power supply. Australia utilised both pumped storage hydro and battery energy storage to maintain grid stability and energy reliability. Vietnam has

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[40] AEMO (2021), *Application of advanced grid-scale inverters in the NEM* [PDF], accessed 20 April 2023.

[41] Under current AEMO guidelines, inverter-based resources are permitted to offer system restart ancillary services. AEMO (2020), *SRAS guideline system restart ancillary services* [PDF], Fig. 2, accessed 26 April 2023.

[42] Not including self-consumption for RTS

strong potential for both these solutions, however these technologies function differently to coal and hydro which were the historic solutions; and therefore, four recommendations are made to unlock zero carbon dispatchable power in Vietnam.

1. **Change the planning strategy for new generation capacity:** historically, Vietnam's planning approach, dictated by the Power Development Plan (PDP), starts by projecting future electricity demand and then identifying the additional baseload and peaking load capacity needed to meet this demand. This approach has been partially[43] successful before the introduction of VREs when Vietnam's power development strategy has relied on fossil fuels for baseload and hydropower for peaking capacity. To unlock further VRE deployment Vietnam needs a new strategic orientation for power planning, which maximises deployment of 'base-cost' VREs and then supplements the bulk addition of VRE with targeted addition of dispatchable/flexible power sources.

2. **Accelerating large-scale energy storage (battery and pumped hydro):** Australia has utilised utility-scale batteries (e.g., Hornsdale) and pumped storage hydro (e.g., Snowy 2.0) to provide flexible power sources in the NEM. Both these technologies have high potential in Vietnam. The Bac Ai pumped storage hydro project is Vietnam's first, and currently only, PSH project.

   - For energy reliability, Vietnam should accelerate the deployment of PSH and ensure that power purchase agreements (PPAs) reflect a usage profile compatible with VREs. A strategy to scale the deployment of PSH to the GW-scale should be developed and integrated into the PDP process.

   - For grid stability, utility-scale batteries provide a good option for managing variability at short time-scales, and also provide local solutions to grid congestion. Vietnam should consider deployment of several large batteries in southern Vietnam, first to balance variability of existing and transitional wind and solar projects, and then to unlock future deployment of VRE in the south. In locations where IBR density leads to system strength deficiencies, or when inertia shortfalls may occur, synchronous condensers may provide a lower cost solution.

3. **Accelerating and expanding market reforms:** The technology for dispatchable power supply in Vietnam is available and proven (see above), however, the Australian experience demonstrates that actual deployment is contingent on the presence of an open and fair market. First and foremost Vietnam should accelerate the introduction of a functioning wholesale electricity market including enabling price discovery for new generation capacity. As noted in the FE-V Generation paper, price discovery is the fundamental

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[43] It should be noted that even in 2010 – 2018, prior to the advent of VREs in the Vietnamese grid, there have been significant issues with power development planning primarily because the rapid rates of growth in electricity demand have required unprecedented levels of investment which has resulted in commission delays and significant energy reliability issues.

feature of the Australian electricity system that has resulted in all new generation addition coming *exclusively* from renewables. Enabling price discovery will allow Vietnam to maximise the addition of 'base-cost' (i.e.., the cheapest) VRE capacity.

To unlock deployment of dispatchable sources, additional markets could also be added to the Vietnamese system. In Australia - financial compensation for the provision of Frequency Control and Ancillary Services (FCAS) has been essential for utility-scale batteries, with price discovery enabled by real-time FCAS markets. The introduction of such financial payments for such services, whether by real-time markets, capacity payments or other mechanisms, in Vietnam would change the economics of dispatchable power and can provide rapid solutions to grid stability.

4. **Re-purpose existing hydropower:** Vietnam has a large, established fleet of 22 GW of hydropower projects; 59 % of this fleet is under ownership of State-owned Enterprises (SoEs). Over the past two decades the role of hydropower has shifted from primarily base-load to peaking supply to support fossil fuels. This shift has suited hydropower where Vietnam's monsoonal climate compromises the reliability of hydropower as a baseload source during the dry season but has made it useful for peaking supply, es also for dispatchable supply in support of VRE. Vietnam should consider repurposing operations of some of its hydropower fleet in the central region to provide energy reliability to existing and transitional VRE projects.

   Although PDP8 does not explicitly mention inertia and system strength, these power system security measures may constrain potential capacity for wind and solar while maintaining grid stability. This is more likely after 2030, since the planned capacity expansion in wind until that time is supported by domestic and imported LNG generation capacity. However, it will become increasingly important to monitor these aspects of the Viet Nam power system as the instantaneous IBR fraction of generation increases over time. It is also desirable to give advance consideration to the ability of inverter controllers to be upgraded, at reasonable cost, to meet new standards of technical performance such as fault ride-through and frequency support.

## Issue 2 - Power System Operator capability to maintain grid stability and energy reliability

### B1 - Problem Context (What): Changing capability of power technology devices to provide grid services

As mentioned above, the mix of electricity generation globally, but also in Australia, is changing significantly from being dominated by dispatchable, synchronous, spinning machine generators powered by the combustion of high greenhouse emissions fossil fuels, to becoming more reliant on variable renewable, low emissions, inverter-based generation such as wind and solar. This transition is being drive by a combination of reducing costs of renewable generation and ambitions to reduce greenhouse emissions. Individual wind and solar farms commonly generate smaller quantities of electricity than fossil fuel generators, and therefore a greater number of them are required to meet the same demand. In addition to the challenges to grid stability and energy reliability, the larger number of generation plants can make the job of the power system operator even more complex. They must consider not only variable energy resources, managing grid stability with inverter-based resources, but also a larger number of generators.

## B2 - Strategic setting (Why): system operator dispatch decisions are more complex

### Grid congestion and curtailment

The choice of which generators to supply power to the network and how much power to supply, at any given point in time, to meet power demand where load is located, determines the flow of electrical power across the transmission network. These power flows must be within the technical operating envelope of generators and must be within the capacity of the transmission network. Total losses of energy due to network resistance and conductance are also determined by the pattern of power flows.

The power system operator will generally select which generators should actively supply power, and how much each should supply, aiming for a combination of both low power losses in the transmission network, and low-cost generation. If there is insufficient capacity in the transmission network, some transmission links can have too high losses, or can reach the limit of their carrying capacity. This constrains the system operator from selecting what would otherwise be a lower cost dispatch of generation. In such circumstances the transmission grid can be described as congested, and the lower cost generation that is prevented from being dispatched can be described as curtailed relative to an uncongested network.

Because of the extended geographic distribution of an increasing proportion of power generation being supplied by variable renewable resources (for example, from Renewable Energy Zones (REZ) in regional areas[44]), there is a likely relative increase in grid congestion and generation curtailment.[45] If there are insufficient renewable resources or there is insufficient network capacity to move the power from renewable energy zones to where it is required, it will adversely impact the reliable supply of electrical power.[46]

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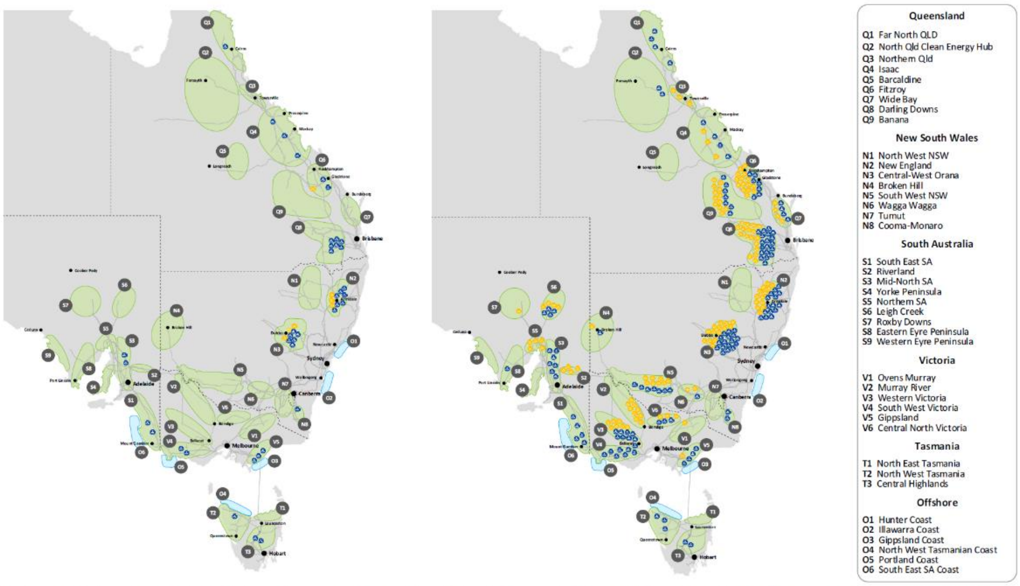
[44] AEMO (2022) *Appendix 3. Renewable energy zones* [PDF], AEMO website, accessed 26 April 2023.

[45] AEMO (2021) *Q&A: Connections to the Western Victoria transmission network* [PDF], AEMO website, accessed 26 April 2023.

[46] Sorensen, J (2023) *Curtailment due to congestion: what's the state of play?*, Battery Storage and Grid Integration Program website, accessed 24 April 2023.

**Figure 4 |** REZ development in the Step Change scenario - 2019-30 (left) and 2049-50 (right)

*Source: Figure 15 from AEMO (2022) [2022 Integrated System Plan (ISP)]*



† AEMO has updated the REZ boundaries for N5 aligned with geographical area of the SWNSW REZ in Schedule 1 of the draft REZ declaration, available at https://www.energy.nsw.gov.au/sites/default/files/2022-03/Draft%20South-West%20REZ%20Declaration.pdf. AEMO will update all relevant parameters in the 2024 ISP.
‡ EnergyCo is in the early stages of planning for two new REZs in the Hunter-Central Coast and Illawarra regions of New South Wales, as set out under the New South Wales Electricity Infrastructure Act 2020. These REZs are not shown because they are not yet geographically defined.

## Operational grid security

Power system security is maintained by ensuring that the operation of generators supplying power to the network is always such that any power system disturbance created by a credible contingency will not result in equipment protection settings being violated, as this could risk a cascading connection failure[47]. Contingencies[48] include the unplanned disconnection of a large generator, load, or transmission link, or an electrical fault that results in a sudden significant flow of power to the fault location.[49]

The response of the power system to a contingency event at any point in time depends on which generators are operating, their power output setpoint and output control settings, which transmission links are active, and the dynamical characteristics of the loads being served. Power system operators typically have authority to determine which major generators are operating, their power setpoint, and operation of the transmission network, but have less authority to control loads.

To maintain system security, system operators select the power setpoint of major generators and transmission network such that sufficient power is generated to meet demand and transported to customers over the transmission network within the physical capabilities of the generators and transmission network, and so that the resulting configuration is stable against small mismatches. The

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[47] Such as the 2016 electrical blackout in South Australia, see Grids Discussion Paper.
[48] AER (2018), *The Black System Event Compliance Report*, [PDF], accessed 28 April 2023
[49] AEMO *Power system disturbances*, AEMO website, accessed 26 April 2023.

system operating setpoint is selected to further ensure that this can be maintained subject to a credible contingency. Furthermore, after a contingency event, the power system operating setpoint may not be secure against another credible contingency, and the system operator will usually eventually reselect an alternative stable operating setpoint.

The selection of an appropriately secure power system operating setpoint that is also economically responsible (that is, does not require the dispatch of more expensive power generation than is necessary), is a complex calculation that must be completed sufficiently quickly to address the constantly changing demand (and renewable resource availability) conditions.

Power system operating conditions required for security of supply when generation is primarily provided by synchronous generation are relatively well understood. In contrast, inverter-based generators have different disturbance response characteristics which are presently less well understood. Because wind and solar resources are intermittent, generation that relies on these resources can not necessarily be dispatched at any time. If the number of major generators increases, as may be the case for renewable generation plants that are typically smaller capacity than major fossil fuel plant, the selection calculation will become more complicated. Each of these factors increases the need to understand the security implications of renewable IBR and improved methods of calculating appropriate operating points for the power system.

## B3 - Solutions (How): Improving power system operator capability to maintain grid stability and energy reliability

### Improving the assessment of grid stability

To address the issues of grid stability created by increased numbers of IBRs in the system, analytical tools that help evaluate the operation of the power system need to be developed. These tools must capture the interactions and impact of IBR control algorithms that can be detrimental or beneficial to the power system's stability and performance and should assess stability margins, which is particularly challenging with time-domain analysis tools.

The operator will also require tools and methods to aid real-time decision making and management of power system security. Existing tools are based on power system phenomena relevant to synchronous machines and so will require re-evaluation. This will require faster processes and new methods to identify the emerging issues brought on by the transitioning power system.

The most critical processes identified to be developed to address these issues in Australia are:

- Stability margin evaluation: tools to assess non-linear stability margins using black-box models and evaluation of stability at multiple operating points

- Small-signal stability screening methods: procedures to use impedance-based methods for stability screening and linear analysis techniques with black box IBR models.

- Voltage stability boundary: tools to identify new boundaries between source and sink regions and recognise voltage stability boundaries as new constraints/criteria for system operation.

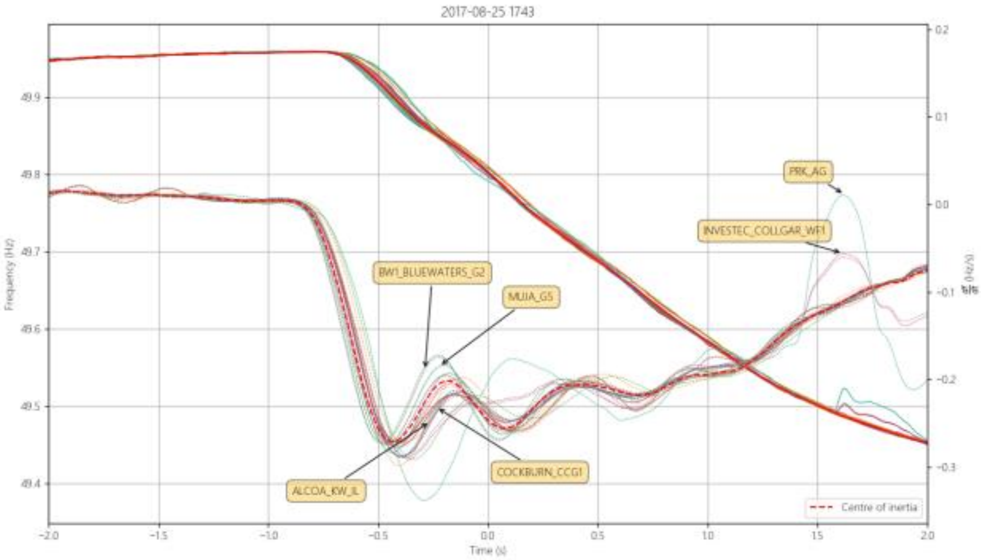
- Voltage control and collapse recovery: improvement in how loads and IBRs are considered in voltage and reactive power control tools, and tools to assist operators with over-voltage mitigation due to an increase in IBR output.

Preliminary work in this area is demonstrating methods of analysing the characteristics of individual IBR so that their overall stability performance when interacting with each other across the transmission grid can be assessed more quickly.[50] The alternative is running numerous, computationally intensive, high (time) resolution simulations that are time consuming and slow.

## Improving coordination of grid services

**Figure 5 |** Example frequency response after a generation contingency event in the SWIS

*Source: Figure 6 of AEMO (2019), Contingency Frequency Response in the South West Interconnected System (SWIS)*



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[50] Dutta et al. (2023) *Analytical methods for determination of stable operation of IBRs in a future power system*, CSIRO website, accessed 26 April 2023.

The system operator uses essential (power) system services, such as frequency and voltage control, to keep the electricity grid stable. In modern power systems, system services determine:

- The operation and planning of the electricity grid across all time scales
- The required characteristics of the technologies connected to the power system, and
- Through commercial mechanisms, the incentives to innovate and invest and to do so equitably.

As grids transition to decentralised, variable and IBR technology, and consumer uptake of DER continues to grow, current state-of-the-art services (e.g., capacity adequacy, ancillary services, etc.) are becoming no longer fit to meet future service requirements. There is a danger of developing electricity grids that are costly, unreliable, and not resilient.

Australian G-PST work is focusing on five areas of essential system services to effectively navigate the energy transition:

1. Technical Domain - Defining system requirements to maximise the DER hosting and more efficient demand response
2. Frequency support services arrangements - Specification of performance parameters for very fast frequency response, capacity requirements of FFR resources in the Australian network.
3. Voltage support services arrangements - Identifying capabilities of conventional Volt/Var/online tap changing transformer equipment and establishing the orchestration requirements for distribution network storage
4. Performance Assessment Metrics - Evaluating existing metrics used to assess the quality of essential services, especially for services in IBR dominated grids.
5. Financial Domain - Revising existing economic aspects of frequency and voltage support services Integrating new services so that they are economically viable, including for DER in the distribution grid in coordination with generation and transmission services

Key outcomes are pathways to:

- Optimise essential service provision from new technologies
- Integrate system services provided by DER

- Facilitate provision of system services necessary to support further major network changes such as electric vehicle uptake

## Improving informational support for Power System Operators

The central control room is the nexus of the modern interconnected electricity grid. From these, operators and utilities monitor demand, coordinate the dispatch of generation, and ensure sufficient essential services are available to support the efficient transfer of electrical energy across the grid, and at all times. Increasingly, climate-driven events and ageing equipment are resulting in incidents that the load dispatch control centre must manage while ensuring reliable supply to consumers. The increasing decentralisation, variability, and overall trend towards an IBR dominated grid are creating gaps in the toolsets and processes of the dispatch control centre.

Many control rooms were designed early in the era of large-scale electricity grid interconnection and have not significantly changed since. They cannot effectively manage our future power system; operations, and the way power system operators interact with the system, will have to change rapidly.

Australian G-PST research is planning the Control Room of the Future (CROF), highlighting the functions, processes, tools, and data that must be replaced, expanded, and developed to maintain effective management of the power system.

> *For AEMO, the CROF roadmap supports the "Real Time Operations" and "Operational Planning" roles. These roles are situated within the context of AEMO's other roles, and within the context of other power system stakeholders, in AEMO's Engineering Framework[51].*

Priority areas to support this are:

- Functional & capability model and architecture
- Data modelling and streaming
- Energy and Market Management Systems
- Operators and human factors
- Buildings, facilities, and hardware

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[51] CSIRO (2023) GPST Topic 3 – Control room of the future, CSIRO website, accessed 26 April 2023, p9.

## B4 - Reflections on Australian experience: Operational enhancements to improve grid stability and energy reliability

In terms of improving operations to manage grid stability, the Australian Energy Market Operator (AEMO) has developed an Operations Technology Roadmap to improve load dispatch and system control capability, including a power system simulation platform to better support real time operations.[52]

> *The roadmap is intended to build on work carried out by EPRI and Strategen for CSIRO in 2021 as part of the Global Power System Transformation (G-PST) initiative. It is tied in directly to ongoing AEMO initiatives, in particular the Engineering Framework (EF), as well as the AEMO future state architecture project.* [53]

The OTR is focused on ensuring core operation capabilities are equipped with tools to manage the overhaul of the power system in response to decarbonisation and decentralisation. Using operational data, the expected evolution of 10 operational tools were modelled to inform decision making around operator human factors, buildings and facility designs. This ensures operation hubs stay ahead of the power system transformation to at least 2030.

The OTR is directly tied to the ongoing Engineering Framework (EF), ensuring a complete data map of the NEM network. This data is streamlined and used for real-time operational & market management and centralised network model management. Allowing it to be digested through enhanced control rooms for operators to combat new era problems such as vast quantities of new inverter-based resources (BESS, FACTS, VPP) and the weather dependency of data.

In 2019, new regulations in the NEM mandated collection of static device information of all DER[54], this information has been used in power system modelling application such as the "Connection Simulation Tool". The recently developed software platform allows market participants to access power system simulation capabilities, to help understand the implications for the operational grid stability of new connections. [55]

In 2017, the Australian Energy Market Operator (AEMO) established a three-year Demand Response Short Notice Reliability and Emergency Reserve Trader (RERT) Trial to demonstrate how demand response could play a role in maintaining system security and reliability during periods of extreme demand. The successful trail was rolled out across 10 funded projects in NSW, Victoria and South

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[52] AEMO *Operation Simulator*, AEMO website, accessed 24 April 2023.
[53] AEMO (2022) *Operations Technology Roadmap*, AEMO website, accessed 24 April 2023.
[54] AEMO (2019) *Maintaining Power System Security with High Penetrations of Wind and Solar Generation*, AEMO website, accessed 1 May 2023
[55] AEMO *Connections Simulation Tool*, AEMO website, accessed 24 April 2023.

Australia, delivering more capacity with each successive year and totalling over 200MW upon its conclusion in 2020.[56]

Following the trail, the Wholesale Demand Response Mechanism (WDRM) was established in the NEM in October 2021. The WDRM allows consumer participation in the wholesale electricity market through their service providers. Service Providers receive payment associated with the scope of participant response, measured in MWh against a baseline estimate electricity price. By flattening peak-demand curves at times of high electricity prices or scarcity, consumers are paid directly through incentives from the Service Provider as well as indirectly through reduced electricity prices on the aggregate.[57, 58] Allowing system operators to call on demand response provides an additional option to reliably supply energy to the rest of the power system as needed.

## B5 - Reflection on Vietnamese significance

In addition to the solutions suggested in Issue 1 – B5, the Australian experience identifies additional planning and operational solutions which have relevance for Vietnam.

1. **Maintain spatial approaches to power development planning:** Vietnam, like Australia, is experiencing significant issues of grid congestion which point to underlying issues in how new generation is planned. In Australia, Renewable Energy Zones which take a geographical approach to generation planning that also incorporates characteristics and needs of transmission and distribution systems. Joint planning of generation capacity and network development is recommended by PDP8 as "Develop electricity according to the principle of overall optimization of the factors of generation source, electricity transmission, distribution, and economical and efficient use of electricity." In general, this requires network constrained operational dispatch studies that account for renewable resource variability, requirements for flexible generation, emergency reserve capacity, distribution network limitations and system security constraints.

2. **Modernise operations and tools of the Central Control room:** The central control room is the nexus of the modern interconnected electricity grid. From these, operators and utilities monitor demand, coordinate the dispatch of generation, and ensure sufficient essential services are available to support the efficient transfer of electrical energy across the grid, and at all times.

    - Recalibrating power system operating set point

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[56] Australian Renewable Energy Agency (ARENA)(2020) *Demand Response Short Notice Trial RERT Trial Year 3 Report*, ARENA website, accessed 24 April 2023.
[57] AEMO *Wholesale demand response mechanism*, AEMO website, accessed 24 April 2023.
[58] AEMO *Reliability and Emergency Reserve Trader (RERT)*, AEMO website, accessed 24 April 2023.

- Develop tools and methods to aid real-time decision making and management of power system security. Existing tools are based on power system phenomena relevant to synchronous machines and so will require re-evaluation. This will require faster processes and new methods to identify the emerging issues brought on by the transitioning power system. The most critical processes: stability margin evaluation, small-signal stability screening methods, voltage stability boundary, voltage control and collapse recovery.

- This is consistent with the PDP8 recommendation to "Modernize information and data systems, automation and control systems to serve the dispatching and operation of the power system and the electricity market." At the time of writing, AEMO calculates generation dispatch setpoints at intervals of every 5 minutes, and in the near future will also manage frequency control ancillary services at time scales of as little as 1 second.

## Issue 3 - The capacity of transmission and distribution networks to meet energy demand with high reliability, irrespective of the location and fluctuation of energy sources

### B1 - Problem context (What): Increasing transmission capacity requirements, new locations

Energy demand typically increases as the economy that it supports grows, although energy efficiency measures can act as a counteracting influence (see the Consumer Demand DP[59]). In Australia, final energy demand has increased by an average of 0.6% over the decade to 2022, while GDP has grown by an average of 2.3%.[60] The goal of decreasing greenhouse emissions can further increase demand for electrical energy in particular. While Australian electricity demand has grown by only 0.6% pa over the past decade, looking forward, electricity demand in the NEM may almost double by 2050 to more than 320 TWh, from just under 180TWh in 2022.[61] This is because switching energy sources, from higher emissions fuels to electricity supplied from low emissions renewable resources, is increasingly becoming a cost-effective emissions reduction option, with 150 TWh of new electricity consumption expected from fuel switching.[62]

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[59] Luke, C., Mickle, M. (2023). *"Future Electricity Vietnam – Future Demand"*. A discussion paper prepared for the Central Economic Commission of the Communist Party of Vietnam. Hanoi, April 2023.
[60] DCCEEW (2022) *Australian energy update 2022*, Table 2, DCCEW website, accessed 26 April 2023.
[61] AEMO (2022) *2022 Integrated System Plan (ISP)*, p9, AEMO website, accessed 24 April 2023.
[62] See footnote above, p32.

However, renewable energy resources such as wind and solar may not be located near population centres and industries where electricity is required, or near existing generators. In the NEM, the most favourable renewable energy resources are located in Renewable Energy Zones (REZ) that are not located near population centres, which are generally along the coast.[63] Accessing these resources requires new electrical transmission and/or distribution infrastructure to connect power to its destination. Intermittent renewable energy, which is variable over time, will typically require greater transmission capacity than would be required to transmit the same amount of electrical energy at a more constant rate, to accommodate peak power requirements.

Each of these factors implies a need to build, and therefore plan, significant new transmission and/or distribution infrastructure capacity.

## B2 - Strategic setting (Why): changing patterns of power flow

### Existing transmission infrastructure must be developed to meet future needs

Transmission infrastructure capacity typically needs to be developed (replaced and augmented) over time to meet the changing needs for service. Even if the demand for operational electricity (that is, electricity that is generated 'centrally' rather than within the distribution network) slows or declines[64] (see the Consumer Demand DP[65]) it is still often necessary to build new transmission capacity to service changing patterns of power flow. However, constructing new transmission infrastructure is costly. Deciding how much new transmission infrastructure will be needed - based on the expected changes in future demand and options for generation, and where it should be routed, is a challenging problem.

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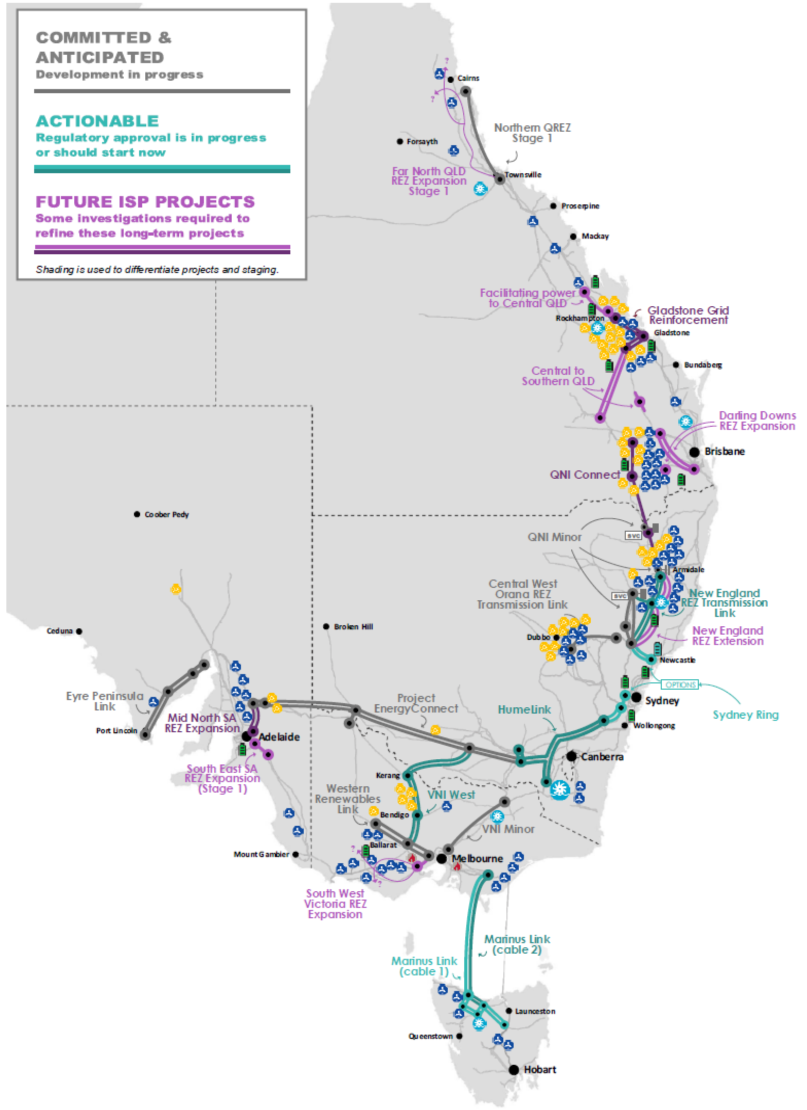
[63] See footnote above.

[64] 0.21% pa average growth projected between 2023 and 2030, http://forecasting.aemo.com.au/

[65] Luke, C., Mickle, M. (2023). "*Future Electricity Vietnam – Future Demand*". A discussion paper prepared for the Central Economic Commission of the Communist Party of Vietnam. Hanoi, April 2023.

**Figure 6 |** Map of the network projects in the optimal development path



† Additional projects to expand REZs and upgrade flow paths after 2040 are highly uncertain, vary significantly between scenarios, and are not shown on this map. See Appendix 5 for more information.

## Changing geographies of power flow, grid congestion and renewable energy curtailment

Planning how to maintain and upgrade transmission infrastructure capacity and build new transmission links is further complicated by increasing possibilities for locating new power generation, and new options for choice of transmission technologies such as High Voltage Direct Current (HVDC) transmission.

To enable wind or solar resources to supply power to the network may require new transmission links to be built to connect to the locations where there are good renewable resources. As new generation locations are developed in Renewable Energy Zones (see Generation Discussion Paper[66]), the patterns of power flows across

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[66] Kenneth, B. (2023) *"Future Electricity Vietnam – Future Generation"* A discussion paper prepared for the Central Economic Commission of the Communist Party of Vietnam. Hanoi, April 2023.

the transmission network will change, and it may become appropriate for some existing transmission links to be upgraded or new links to be developed to bypass links that would otherwise be congested, as such congestion could result in undesirable generation curtailment.

## Legacy network design approaches

In the past, the design of transmission and distribution network infrastructure was typically based on the assumption that flows of power would be mostly in one direction, from the location of existing generators to the location of existing loads.

With the expectation of increasing quantities of DER at the customer end of the transmission network, it is plausible to expect 'reverse' power flows occurring within distribution networks and significantly lower net loads in the transmission network, at times of peak solar production. If distributed energy resources are sufficient, transmission network nodes that were historically loads may even become net sources of power at some times.

Distribution networks historically have not been designed to accommodate significant power export by customers. Such operations may adversely affect local distribution power quality without being immediately detectable by the network operator. This may include undesirable voltage levels outside targeted values, or current flows that exceed technical limits, particularly as power flows may become more unbalanced across phases. Similarly low, or reverse, power flows on the transmission network may put parts of the transmission network into patterns of flow that had not been contemplated during the original design. This would require either network upgrades to accommodate, or operational limits to be placed on distributed generation exports (that is, curtailment).

## Financing of transmission and distribution infrastructure

Transmission and distribution infrastructure is expensive. In Australia the wholesale cost of electricity, that is, the cost of generation, contributes to about a third of the retail price charged to the customer. Transmission and distribution infrastructure costs represent slightly less than half of total retail costs67, and the majority of network infrastructure costs are in the low voltage distribution network.

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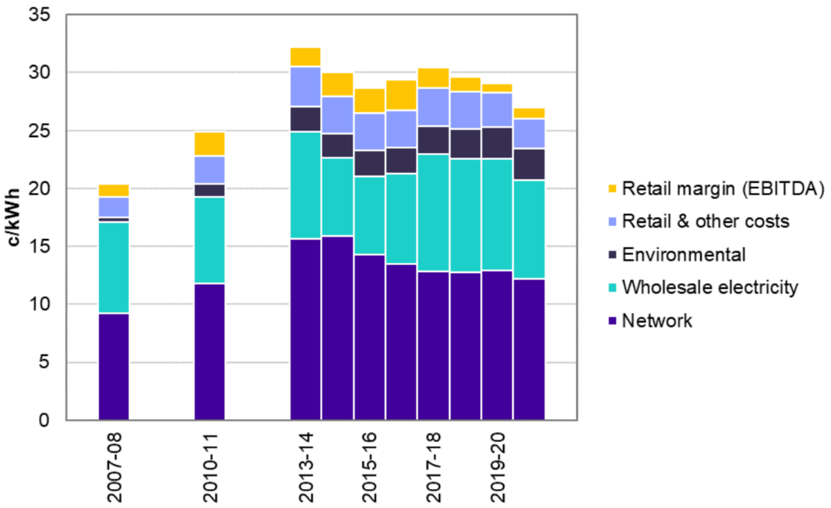
[67] Australian Competition & Consumer Commission (ACCC) (2021) *Inquiry into the National Electricity Market – November 2021 report*, ACCC website, accessed 24 April 2023, Figures 2.2-2.5.

**Figure 7 |** Disaggregation of residential electricity price into cost components

*Source: Figure 2.2 of ACCC (2021) [Inquiry into the National Electricity Market - November 2021 report]*

*Average residential customer effective price across the NEM from 2007–08 to 2020–21, real $2020–21, excluding GST*



Source: ACCC analysis based on retailers' data.

Infrastructure such as transmission and distribution networks consist of long-lived assets. They therefore have relatively large up-front costs for construction, whereas customers would make only ongoing payments for the services these provide.

If transmission or distribution network construction costs are to be funded by investors seeking a financial return on investment, those investors would generally need to be confident that ongoing financial returns are of sufficient quantity and reliability to compensate for the upfront costs. However, since infrastructure such as an electrical network is a natural monopoly, allowing the asset owners to set the prices for infrastructure services would be economically inefficient.[68]

## B3 - Solutions (How): Power Transmission and Distribution Network Planning and Development

### Improving transmission network planning

The increasing operational and technological complexity of power systems, combined with uncertainty in the future system, market, and policy developments, are diminishing the effectiveness of traditional deterministic planning approaches. The key problems and challenges that need to be addressed to plan for and build the power system of the future are:

- The operation of low-carbon systems dominated by renewables and distributed energy resources (DER) and with

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[68] AEMC *Network regulation*, AEMC website, accessed 24 April 2023.

increasing coupling with other energy sectors will require new modelling requirements and tools.

- Long-term uncertainty is increasingly influenced by factors, including emerging technologies and business models, policy environments, and climate change, that represent formidable challenges to system reliability and resilience.
- More sophisticated and flexible representations of the possible futures are needed, along with new decision-making frameworks and tools to deliver plans that optimise outcomes across multiple scenarios.
- New metrics and methodologies are needed that account for the technical and economic risks faced by multiple stakeholders during the energy transition.
- The interface between power systems and other energy systems and sectors (i.e., gas, hydrogen, transport, heavy industry including thermal applications and energy exports) needs to be designed to capture the impact of and flexibility created by multi-energy systems and sector coupling in planning studies.

To meet these challenges, Australia is creating tools, methods, and frameworks to plan the future of the electric power system by considering the following issues:

1. Quantifying long term uncertainty: producing future energy scenarios, investigating climate change impact and uncertainty in policy & market developments.
2. Modelling power system operation: developing both steady-state and dynamic power system models for planning purposes and formulating enhanced security constraints.
3. Assessing reliability and resilience: establishing reliability & resilience metrics, study system-level impact of climate change, identifying credible & non-credible contingencies and characterise DER/IBR responses to different events.
4. Investigating DER: studying the impacts from multi-energy systems, distributed energy markets & demand-side flexibility and DER.

## Understanding the architecture of the power system

Modern electricity systems are more complex than ever, and they will continue to experience unprecedented change during the transition towards decentralised and renewable sources of generation. Critical to managing this increasing complexity is an understanding of the organised underlying structure, or ‘architecture’, of the power system.

The established Systems Architecture engineering discipline is a key for transforming highly complex systems of any type. 'Power Systems Architecture' (PSA) is a generic term for an integrated set of disciplines applied to the strategic transformation of legacy power systems to better meet changing policy and customer expectations. It is based on the combined application of Systems Architecture, Network Theory, Control Theory and Software Engineering disciplines.

In Australia, the architecture roadmap for the power system transformation is being developed to achieve the following:

- Enhancing capacity to navigate the complex structural and operational shifts that are inherent in the large-scale transformation of power systems
- Providing a robust methodological basis for establishing a diverse and informed multi-stakeholder 'community of practice' that is better equipped to collaborate on the wide range of trade-off decisions essential to enhanced system and customer outcomes and an orderly transition
- Significantly strengthening multi-stakeholder engagement, process coherence and transparency as a basis for greater trust and enhanced social license for change.

The process includes:

- Exploring future system objectives
- Identifying emerging trends and systemic issues
- Documenting existing architecture and constraints
- Creating a contemporary issues and directions report
- Exploring future system qualities, properties, and functions
- Developing future architectural options
- Combining into future options and transitions pathways.

Understanding the existing power system architecture will lay the foundation for further developing into new architectures: for coordinating the capability of new power system technologies, regulatory approaches, market designs, and the distribution/transmission interface in a highly distributed, variable renewable energy-based system to support an orderly power system transition.

## Non-network technologies to support reliability: energy storage and decentralisation options

Access to additional energy storage capacity can provide additional options for a power system operator to reduce grid congestion and renewable energy curtailment. Large scale energy storage options include pumped hydro-electric storage (especially off-river to reduce environmental impact), large scale batteries and thermal storage (which also could be associated with solar thermal generation, [69] see Generation Discussion Paper[70]).

Storage can alleviate the constraints due to transmission capacity limits, transmission being movement of energy across space, by – in effect – moving energy across time. It can therefore allow generated power to be available at a different time from when generated, can shift net loads to a different time from the final energy service, or can allow transmission to occur when the network is less congested.

Generally speaking, batteries are most cost effective for relatively short time scale storage of minutes to hours, thermal storage is appropriate for storage of hours to days, and pumped hydro-electric storage is least cost for storage durations of days to months. [71] Hydrogen can also be used as a form of chemical storage on seasonal timescales (see Generation discussion paper[72]).

Battery storage at the customer end of the network could also contribute to the storage options available to the operation of the power system. This includes not only fixed location batteries that a customer might install to make more use of solar PV (or other generation) that they have on-site, but also the batteries in electric vehicles, which are expected to contribute to an increasing proportion of global transport fleets.[73]

## Regulated investment financial returns

There are two obvious alternative options to encourage investors to provide funding for transmission infrastructure without allowing the asset owner to exploit their natural monopoly nature, which could result in undesirably high prices charged for infrastructure services. Investors could provide funding to the asset owner in the form of a loan to be repaid on commercial terms that are independent of the revenues accruing to the asset owner. Alternatively, investors could directly own the infrastructure, with returns derived from revenues from charges to customers for the infrastructure services, on terms of service and pricing that is regulated to ensure both an attractive,

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[69] CSIRO (2023) Renewable Energy Storage Roadmap, CSIRO website, accessed 24 April 2023, see Table 5.
[70] Kenneth, B. (2023) *"Future Electricity Vietnam – Future Generation"* A discussion paper prepared for the Central Economic Commission of the Communist Party of Vietnam. Hanoi, April 2023.
[71] CSIRO (2023) Renewable Energy Storage Roadmap, CSIRO website, accessed 24 April 2023, see Table 5.
[72] Kenneth, B. (2023) *"Future Electricity Vietnam – Future Generation"* A discussion paper prepared for the Central Economic Commission of the Communist Party of Vietnam. Hanoi, April 2023.
[73] International Energy Agency (IEA)(2022) *Global EV Outlook 2022*, IEA website, accessed 24 April 2023, Figures 4-13 and 7-3.

reliable financial return on investment, and that are reasonable for customers.

> *Publicly owned utilities have certain advantages, such as … ability to issue low-cost tax-exempt debt to finance construction…. Often they are financed by general obligation bonds and revenue bonds …*
>
> *Investor-owned utilities (IOUs) are owned by stockholders that typically seek to maximize profits within the framework of regulations governing these types of utilities*[74].

A common approach for the latter option is to allow the asset owner to accrue revenue that is an agreed percentage each year of an agreed value of the infrastructure. The agreed percentage is called the regulated rate of return (RoR), and the agreed value of the infrastructure is called the regulated asset base (RAB). The regulated RoR is typically kept in line with comparably risky investments, and the RAB is typically assessed according to strict accounting rules and any infrastructure investments to be included within the RAB should be approved only according to pre-determined rules.

## B4 - Reflection on Australian experience: transmission and distribution network planning and development

Between 2010 and 2018, transmission planning for the NEM (National Electricity market – East Coast) was undertaken annually, resulting in a National Transmission Network Development plan. Since 2018, however, the transmission system planning function for the NEM now strongly incorporates demand forecasting and generation planning, within the Integrated System Planning process.[75]

The process of developing an Integrated System Plan includes the identification of Renewable Energy Zones, which are selected for their potential for high quality renewable resources.[76] Renewable energy zones a predominantly located along the east/south coast of the country and are expected to take on a roll as "modern-day power-stations"[77]. These identified zones are prioritised for consideration of new transmission development.

There is a growing interest in understanding the architecture of the power system, particularly as it applies to the coordination of distributed energy resources, although there are implications for the entirety of generation and grid management.[78]

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[74] Blazek, C, (2011), The U.S. Electric Markets – Structure, and Regulations, Chapter 3 in M Greer (ed. 2011), *Electricity Cost Modeling Calculations*, Academic Press, ISBN 9781856177269, pp 43-113, , https://doi.org/10.1016/B978-1-85617-726-9.00003-0, viewed 28 April 2023.

[75] AEMO (2022) *2022 Integrated System Plan (ISP)*, AEMO website, accessed 24 April 2023.

[76] AEMO (2022) *Appendix 3, renewable energy zones* [PDF], AEMO website, accessed 24 April 2023.

[77] EnergyCo (n.d) *Renewable Energy Zones*, Online Article, accessed 5th May 2023

[78] AEMO (2018) *Coordination of distributed energy resources* [PDF], AEMO website, accessed 24 April 2023.

New transmission infrastructure investment is subject to a Regulatory Investment Test for Transmission (RIT-T), which is assessed for economic cost-benefit by the Australian Energy Regulator.[79] Any proposed transmission network investment must pass this assessment before being included within the RAB of the regulated owner. A similar regulatory test applies for distribution network investment.

Recent developments in new transmission infrastructure, which are subject to the RIT-T, include

- the Queensland-NSW Interconnector upgrade, completed in 2022, representing 300 km of transmission lines, increasing the transmission capacity into Queensland by 460 MW[80.] The upgrades were necessary to make it easier and more efficient to share lower-cost power between the states.

- Project EnergyConnect, started in 2022 in the south-west of NSW, representing 900 km of 330 kV AC[81]. The project will connect SA with NSW, passing through multiple renewable energy zones. This connects a possible 10million people with low-cost, abundant green energy, improves competition between other energy generators and improves interstate transmission capacity by around 800MW.

- the Victoria to NSW Interconnector (West), a proposed transmission upgrade, representing 400 km of 500 kV transmission and increasing the transmission capacity by about 1800 MW[82]. Currently in RIT-T stage, the project has been proposed to maintain Victoria's supply reliability in the wake of/in preparation for the withdrawal coal-fired generation plants in the region. The project will unlock REZ's in the region, as well as vastly increase power sharing capabilities between the two states.

However, non-network solution alternatives to transmission investment are also considered. Demand management is permitted as a non-network infrastructure investment alternative. Incentives for implementing demand management measures by Australian networks include a Demand Management Innovation Allowance Mechanism (DMIAM)[83] and a Demand Management Incentive Scheme (DMIS).[84]

DMIAM funding is available to financially support transmission networks to conduct research and development into new demand management schemes that are promisingly cost effective. The DMIS

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[79] Australian Energy Regulator (AER) (2018) RIT-T and RIT-D application guidelines 2018, AER website, accessed 24 April 2023.
[80] Transgrid (2021) Queensland to NSW Interconnector Upgrade [PDF], accessed 28 April 2023
[81] Project Energy Connect (2022), Project overview, [PDF], accessed 28 April 2023
[82] AEMO (2023), VNI West Consultation Report – Options Assessment, [PDF], Accessed 28 April 2023
[83] AER (2021) Demand management innovation allowance mechanism – transmission, May 2021, AER website, accessed 24 April 2023.
[84] AER (2021) Demand management incentive scheme (DMIS) assessment 2019-20 and 2019, AER website, accessed 24 April 2023.

provides financial support to distribution networks to actually implement demand management schemes that delivers net cost savings to customers.

In terms of other non-network investment to manage energy reliability, Australia is projecting a substantial increase in the requirement for, and availability of, energy storage (See also Kenneth, B. (2023) *"Future Electricity Vietnam - Future Generation"*). Most significantly:

- an additional 2 GW of pumped hydro-electric power storage with 350,000MWh (175 hours) of storage capacity is currently under construction in NSW (Snowy 2.0) and expected to be operational within the next few years[85]. The project will use surplus energy when demand is low to pump water to an elevation before releasing it to generate energy when demand is high. The project will cost between A$3.8-$4.5billion and hold enough energy to power to three million homes for a week[86].
- up to 50 GW storage by 2050 in the east coast NEM, which represents a little more than a fifth of generation capacity, including availability from electric vehicles and some from households associated with RTPV.[87]

Despite expecting significant increases in transmission and storage capacity, future projections based on least cost planning nevertheless also anticipate increasing curtailment of large-scale renewables.[88] This is because some renewables curtailment is more cost-effective than additional storage or transmission, and this can be considered “overbuilding” of generation capacity (in a physical, rather than economic, sense).

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[85] Snowy Hydro *About - Snowy Hydro*, Snowy Hydro website, accessed 24 April 2023.
[86] ibid
[87] AEMO (2022) *2022 Integrated System Plan (ISP)*, AEMO website, accessed 24 April 2023.
[88] Ibid, Section 3.5

## B5 - Reflections on Vietnamese significance[89]

Investment, construction, management and operation of the transmission and distribution grids are the responsibility of EVN. EVN assigned NPT to be responsible for 500 kV and 220 kV transmission grids and substations and some 110 kV transformers in specific locations while Power corporations (there are five Power corporations) are responsible for 110 kV and lower voltage networks. Development of the transmission grid follows the power development plan which is prepared every five years, increased to 10 years following the revision of the electricity law in 2012 while the development of transmission grid is stipulated in the provincial socio-economic development plans.

There are several issues with the current arrangement, in particular considering future development of the power sector.

First is the investment requirement for the transmission grid. The forecast capital requirement for grid development under draft PDP8 is approx. $US 15.2-15.6 billion for the 2021-2030 period (an average of $US 1.5-1.6 billion per year) and $US 21.7-35.1 billion for the 2031-2050 period (an average of $US 1.1-1.8 billion per year). This capital requirement is very challenging for EVN to mobilize, particularly in the context that the current average retail electricity tariff is significantly below the level assessed by the World Bank for full cost recovery ($US 0.079 per kWh versus $US 0.12 per kWh). It is reported that from 2016 to 2021, NPT invested $US 4.7 billion for the transmission grid. On average, the investment was $US 0.94 billion per year and this was already a great challenge for EVN.

Furthermore, investment required for the low voltage distribution grid is also likely to be extremely costly, as the flows of power provided by large generators between the transmission network and end-users continues to grow. Although the PDP8 anticipates that up to 50% of commercial and residential buildings will be supplied by RTS by 2030, this will reduce the requirement for investment in distribution network only if this energy can be used by consumers at times of peak electricity demand. Permitting some export of RTS within a local distribution network, although not currently anticipated by PDP8, may allow customers energy demands to be met with even less requirement for network investment. Taking full advantage of export RTS to reduce the need for distribution network capacity will require battery storage within the distribution network, and the least cost mix is likely to include both utility-scale and behind-the-meter storage.

Second, future power source will be dominated by renewable energy sources (wind and solar). Their resources are not located near the load centres meaning substantial transmission development is expected to transmit power to where they are consumed.

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[89] See p21 of AMPERES_VN_Scoping_Study_09-11-2021_F-F-F.pdf ‘Component A’ and ‘Component E’

For future grid, the government can promote the concept of renewable energy zone to guide transmission grid development and employ system approach for the development of backbone transmission system and can use the Regulatory Investment Test for Transmission (RIT-T) for the new transmission.

Even with tools like REZs, RIT-T that attempt to rationalise transmission and distribution investments, the scale of investment required remains likely beyond what the public sector can continue to finance alone. From the above, Vietnam can consider non-state actor to participate in investment and operation of specific transmission lines. In fact, the Government of Vietnam has already seen this challenge and accordingly revised the electricity law to enable non-state actors to make investments and operation of specific transmission lines. The question is how the private sector can participate, under which financial arrangement, and whether changes in the legal framework are required to enable this investment. In Australia's NEM a number of approaches have been utilised to attract investors to transmission infrastructure. Most promising for Vietnam is a model whereby the asset owner is allowed to accrue a fixed percentage revenue (on the asset value, called a Regulated Rate of Return (RoR), which is kept in line with comparably risky investments.

For the reliability of the transmission grid, Vietnam can consider investment of battery storage and for that fee for ancillary service must be first worked out so that the capital investment can be recovered (See Issue 1 – B5).

## Issue 4 - Coordination of Distribution Scale Power Technology Devices for energy reliability

### B1 - Problem context (What): Increasing deployment of distribution scale power technology devices

Rooftop solar PV is becoming increasingly affordable[90], and therefore an attractive option for individual customers to install to supply not only their own electricity requirements, but also to export electricity to the grid[91]. Furthermore, electric vehicles are also likely to grown in number[92]. This represents an additional load on the electrical network, switching from liquid transport fuels such as petrol and diesel. However, it also represents an opportunity manage the timing of electrical load by selecting appropriate times to recharge these vehicles, as well as to exploit their battery storage capacity as an additional option to resupply power to the grid. Stationary small-scale batteries are also reducing in cost, allowing individual consumers to store and discharge electricity at different times of the day. While the

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[90] CSIRO (2022) *GenCost 2021-22 – Final Report*, [PDF], CSIRO Website, accessed 27 April 2023
[91] CSIRO (2022) *Small-scale solar PV and battery projections 2022*, [PDF], AEMO Website, accessed 27 April 2023
[92] CSIRO (2022) *Electric vehicle projections 2022*, [PDF], AEMO Website, accessed 27 April 2023

installation of additional distributed PV generation and new electrical loads could place greater pressure on the distribution network, the ability to choose when to charge and discharge distributed battery storage and when to charge electric vehicles provides options to relieve that pressure by coordinating operations.

## B2 - Strategic setting (Why): uncoordinated distribution scale power technology devices infringe distribution network limits

### Dynamic behaviour of inverter-based equipment

Inverter based distributed generation such as solar PV, batteries and DC power supplies respond to fluctuations in voltage and frequency in a different manner from more traditional resistive loads such as incandescent lights and electric heating, or inductive loads such as motors. Collectively, as the mix of customer connected devices changes, the dynamic response of loads (from the perspective of the transmission network) may change, resulting in changing requirements on the capability of the transmission grid to provide balancing power in response to changing loads. Alternatively, it may become advisable for the standards for the behaviour of distributed energy resources and small-scale loads to be enhanced, for example by being required to be more flexible and controllable, to reduce any adverse impacts of their collective behaviour.[93] On the other hand, the progressive introduction of plant and equipment (loads) that can tolerate higher frequency and voltage deviations may eventually enable power quality standards to be relaxed. Indeed many applications now don't need alternating current power any more, and there are suggestions that[94] electricity users could be provided directly with DC rather than AC power, and there are some emerging implementations[95].

### Limited knowledge of network assets and limited visibility of operations

Recall, as mentioned above, that distribution network infrastructure was typically constructed to allow power flows from centralised, large scale, generators to customers, and was designed to maintain adequate quality of service under those assumptions.

However, the changing nature of loads: with the inclusion of rooftop photovoltaics, distributed batteries, and electric vehicles; resulting in a much wider range of power flow regimes to support, makes it increasingly challenging to maintain power quality. Unmanaged customer demands that include bidirectional flows of power could shift the operational requirements on the distribution network beyond

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[93] AEMO (2021) *Behaviour of distributed rsources during power system disturbances* [PDF], AEMO website, accessed 24 April 2023.

[94] Dragičević, T., Lu, X., Vasquez, J. C., & Guerrero, J. M. (2016). DC microgrids – part II: A review of power architectures, applications, and standardization issues. IEEE Transactions on Power Electronics, 31(5), 3528-3549. doi:10.1109/TPEL.2015.2464277

[95] MicroGrid Knowledge TM (2022), *How a DC microgrid helps over 10,000 Kenyan tea growers bring their product to market*, Online Article, Accessed 28 April 2023

its existing technical limits. Better management through more comprehensive contracts with customers to incentivise them to vary their demand loads and feed-in supply will be required that will help improve visibility.

However, more active management[96] of the distribution network is facilitated by extensive continual monitoring: of voltage levels, current and power flows in conductors, and individual customer loads. It requires detailed understanding of the distribution network topology, and records of the electrical parameters governing the performance of conductors. Because monitoring and active management of distribution networks was not required in the past, much of this basic knowledge of the network structure may be missing, and there may be limited monitoring of operations.

### Distributed energy resources curtailment due to distribution grid congestion

Without active management of distributed energy resources[97], it may be necessary to significantly restrict the export capacity of rooftop solar to ensure that distribution network technical limits are not infringed. However, active monitoring of the distribution network conditions could allow the relaxation of export capacity restrictions for particular periods of time. Furthermore, active management of the timing of loads, or the 'shifting in time' of generation or loads can reduce the need to curtail distributed generation, just as it can for transmission.[98]

## B3 - Solutions (How): Distribution scale power technology device characterisation and co-ordination for energy reliability

### Understanding distribution scale power technology devices: inverter characterisation

Modelling and analysis of DER responses can help system operators to maintain power system security under very high DER penetration. It has been demonstrated that IBRs may exhibit unwanted effects (i.e., disconnection or power curtailment) if exposed to distribution voltage depressions such as those that occur during transmission level faults. This creates a clear threat to system security.

Such inverter technologies will drive energy storage systems, hybrid storage inverters, commercial and industrial systems, and vehicle charging in the future energy system. It is therefore vital to assess the performance of these inverters to the types of faults and grid disturbances that they are exposed to in the current grid.

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[96] Renew Economy (2022), *Rooftop solar switched off for third day, but Thursday looms as crunch in South Australia*, Online Article, Accessed 28 April 2023

[97] ARENA (2022), *DER Market Integration Trials: Summary Report*, [PDF], Accessed 28 April 2023https://arena.gov.au/assets/2022/09/der-market-integration-trials-summary-report.pdf

[98] AEMO (2021) *Solar PV curtailment initiative by SA Government supports the NEM*, AEMO website, accessed 24 April 2023.

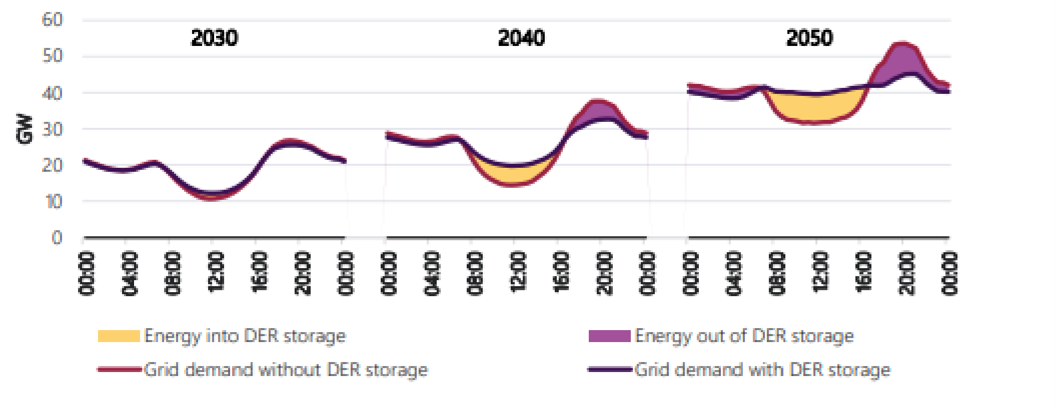
Without an accurate understanding of how inverters operate, it is difficult for system operators to adequately prepare for and respond to disturbance events. G-PST research aims to build a real-world understanding of DER behaviour and develop tools to help system operators to manage the effective integration of DER into the power system. This includes laboratory testing, in-field data analysis, and simulation to build a comprehensive understanding of DER behaviours during disturbances and apply this knowledge to broader system planning and operations. Specific topics that are being explored are:

- DER inverter performance benchmarking
- New DER design innovations and DER management techniques
- Identification of DER security issues
- Dynamics of DER power quality modes
- Data driven techniques for aggregating DER performance data
- Fault and disturbance propagation in the distribution network.

## Coordinating distribution scale power technology devices

**Figure 8 |** Impact of coordinated DER and distributed storage

*Source: Figure 24 of AEMO (2022) 2022 Integrated System Plan*



Investigating the challenges and opportunities from very high levels of DER can make the control and operation of the power system more effective. Increasing levels of DER penetration bring growing uncertainty for the system operator and network planners. DER embedded within the distribution network are generally not operationally visible to the system operator or TNSPs. Instead, they are observed as an aggregated fluctuation in demand at the transmission bulk supply points. This means that net demand seen by the transmission system operator varies drastically with the weather, affecting local settings such as frequency response and/or voltage response (Volt-Watt) functions. Together, this makes the task of operating and planning the power system economically, securely, and reliably much more complex.

In Australia, DER predominantly consists of small-scale rooftop PV installations. These amount to over 20 GW of installed capacity[99] – the single largest category of generation. Operationally, the coordination of so many distributed energy sources and sinks will be a significant task that can have undesirable outcomes for power system operations should necessary changes fail to implement effectively. High priority research activities to address these challenges have been identified by members of the G-PST Consortium as:

- DER Visibility: define the data flows (DER specs, measurements, forecasts, etc.) needed to ensure AEMO has enough DER/net demand visibility to adequately operate a DER-rich system in different time scales (mins to hours).
- Control architecture of DER: establish the role of DER standards in concert with the future orchestration of DER, define the most adequate decision-making algorithm for each DER control approach to achieve DER aggregation and orchestration.
- Communication requirements for monitoring and control: determine the most cost-effective communication and control infrastructure for each of the potential technical frameworks for orchestrating DER and the corresponding decision-making algorithms.
- Ancillary services provided by DER: establish the most cost-effective system services that can be delivered by DER considering the expected technological diversity and ubiquity of DER.
- DER influence on system planning: define the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies, estimate the minimum availability of system services from DER at strategic points in the system throughout the year and across multiple years.
- Institutional challenges: establish the necessary organisational and regulatory changes to enable the provisioning of system services from DER, define the

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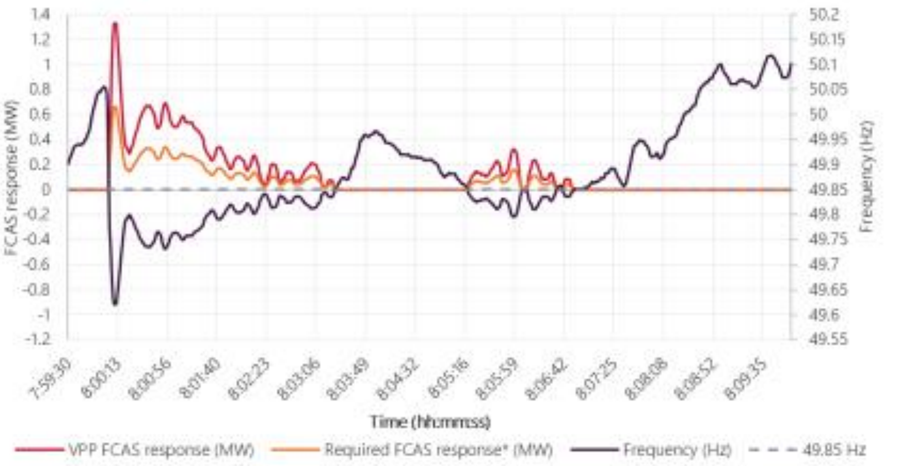
[99] Australian Financial Review, *Rooftop solar hits record 20GW*, AFR Website, Accessed 28 April 2023

necessary considerations of establishing a distribution-level market (for energy and services).

### B4 - Reflection on Australian experience: co-ordination of distribution scale power technology devices for energy reliability

**Figure 9 |** FCAS response of a VPP to contingency event in Queensland in 2019

*Source: Figure 39 of AEMO (2020) South Australia Electricity report*



Australia recently reached a milestone of 20 GW of installed capacity of rooftop solar PV, compared to 90GW of total generation capacity. This represents an increase from 120MW of rooftop solar in 2009, with installations now on more than 30% of Australian households (over 3 million in total)[100]. In 2021, during some five-minute periods, rooftop solar contributed to more than 90% of electricity demand in South Australia.

Regulatory requirements for small-scale inverters have recently been tightened as part of a change to the Australian Standards[101]. These include requirements to remain connected during faults that result in voltage disturbances, response requirements to assist in the support frequency and voltage stability, improved measurement accuracy, enhanced testing requirements and more explicit emphasis on application of the standards to electric vehicle chargers.

There have been several trials and demonstrations of virtual power[102] plants (that is coordinated operation of DER)[103], investigating customer experience, demonstrating the technical feasibility of contributing to frequency control (Figure 9), and identifying regulatory barriers to commercialisation. A virtual power plant utilising 100% hydrocarbon free energy successfully powered the Onslow, WA microgrid for over 80minutes using exclusively DER

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[100] Department of Climate Change, the Environment, Energy and Water. (2023). *Solar PV and Batteries*. Accessed 18 April, 2023.

[101] AEMO (2022), *AS/NZS 4777.2 – Inverter Requirements standard*, Accessed 28 April 2023

[102] AEMO (2021), *AEMO Virtual Power Plant Demonstrations*, Accessed 28 April 2023

[103] ARENA (2018), *VIRTUAL POWER STATION 2.0 – Project results and lessons learnt,* Accessed 28 April 2023

power sources in 2021[104], the first of its kind in Australia. There are various technical challenges to be overcome before large scale coordination of distributed energy resources can be achieved[105]. Other studies have associated the challenges of implementing a market-based solution to the coordination of distributed energy resources[106], noting that this is one option to simplify the data communication flows required for coordination.

Throughout the demonstrations, new Frequency Control Ancillary Services (FCAS) specifications were analysed to ensure grid stability using high-speed meters. The allows rapid network response to external loads and energy price signals[107].

The potential benefits of managing allowable energy exports limits from rooftop via the implementation of dynamic operating envelopes has also been investigated[108]. However, accurate implementation of such calculations requires adequate knowledge of the topology and electrical characteristics of local distribution networks. And quantifying the full potential benefits of such management approaches requires access to representative data characterising distribution networks[109].

Stand-alone power system (micro-grid) trials have also been implemented by individual network companies, including the less densely populated states of Western Australia[110] and Queensland[111]. Regulatory change was required[112] to permit network operators to offer a non-network generation solution to customers. The incentive to provide microgrid solutions lies not only in the reduction of maintenance costs for long and under-subscribed transmission lines, but also in reducing the risk from extreme weather events and bushfires.

One of the electrical power utilities in the north of Western Australia, Horizon Power[113], operates more than forty small-scale electrical power networks, ranging in scale from less than 1 MWh/pa to more than 50 MWh pa consumption, with more than half providing less than 4MWh/pa[114]. There have also been some trials of small-scale grids in Queensland, and guidelines developed for the design of small-scale grids[115], including for industrial applications[116].

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[104] Horizon Power (2021), *Onslow Microgrid Powered Hydrocarbon Free*, Accessed 5th May 2023

[105] ARENA (2022), *Project Symphony Lessons Learnt Report (Milestone02: Build and Integrate)* [PDF], Accessed 28 April 2023

[106] ARENA (2022), *Project EDGE Lessons Learnt Report #2* [PDF], Accessed 28 April 2023

[107] AEMO (2019), *NEM Virtual Power Plant (VPP) Demonstrations Program – Final Design*, Accessed 1st May 2023

[108] AEMO (2022), *The role of dynamic operating envelopes in coordinating and optimising DER*, Accessed 1st May

[109] Geth, F, Brinsmead, T, West S, Goldthorpe, P, Spak B, Cross, G, Braslavsky, J, J 2021, *National Low-Voltage Feeder Taxonomy Study*, EP2021-2759

[110] Western Power (2022), *On the road to 4000 stand-alone power systems*, Online Article, Accessed 28 April 2023

[111] Essential Energy (xxxx), *Stand Alone Power Systems (SAPS) Flyer*, [PDF], Accessed 28 April 2023

[112] AEMC (2020), *Updating The Regulatory Frameworks For Distributor-led Stand-Alone Power Systems: Final report*, [PDF], Accessed 28 April 2023

[113] Horizon Power (2023), *Company Website*, Online, Accessed 28 April 2023

[114] Horizon Power (2019), *Statement of Compliance*, [PDF], Accessed 28 April 2023

[115] ARENA (2019), *PowerWater: Solar/Diesel Mini-Grid Handbook*, [PDF], Accessed 28 April 2023

[116] ARENA (2018), *Hybrid power generation for Australian off-grid mines*, [PDF], Accessed 28 April 2023

## B5 - Reflection on Vietnamese significance

Vietnam also has policies for rooftop solar PV. Decision 13/2020/QĐ-TTg, dated 6 April 2020 stipulates that rooftop solar systems (RTS) can have a capacity up to 1 MW (~1.2 MWp) and RTS project can sell partly or all generated electricity to EVN at a tariff of VND 1943 /kWh or 8.38 US cent/kWh, with standardized PPA for 20 years - applicable only to projects that have COD in the period of 1 July 2019 to 31 December 2020. Beside price incentive, RTS projects enjoy preferential tax, including exemption from import tax for parts which cannot yet be produced locally and preferential corporate tax during their operation phase. These incentives plus the global PV module price drop have made solar PV generation attractive for households, businesses, and industries to install RTS not only as a means of meeting their own demand and therefore reducing their electric bills but also making business by selling the redundant electricity or in many cases selling the entire generation production to EVN.

Statistics from EVN shows that at the end of 2020, a total capacity of 7,785 MW of RTS was installed, accounting for 11% of the total system installed capacity. Compared with the preceding year, these represented an increase of appro. 7,500 MW or 2500% in one year. This huge increase in such a short time has created several issues to the system stability and reliability. These include grid congestion, particularly during the pandemic period when the demand was low leading to curtailment to these sources by EVN. It should be noted that all these RTS sell electricity to EVN, particularly those installed by the industrial sector. They export the dominating percentage of the generation output and some export the entire output. This led to power flow from low voltage to higher voltages and thus created difficulties for NLDC in the system operation.

There have been several attempts to solve these problems. These include a study on installing Scada system for large RTS (100 kW scale) so that NLDC can proactively control these power sources for the system operation. While this requirement takes time to be enforced, NLDC has developed a software to forecast day ahead power output of RTS by province and region.

Administrately, EVN is requesting RTS owners to supplement required design documents and will refuse the connection for RTS that fail to supplement (It is considered as a way to relieve the problem caused by these systems technically, not to mention the financial problem caused by them due to higher price paid to these systems than the average retail tariff). At the same time, EVN declines grid connection for new RTS even they do not export redundant power into the grid saying that there is not yet a new guidance from MOIT.

From the long- term policy perspective, PDP8 tends to continue to support RTS development however only for those for self-consumption and encourages installation of battery storage to increase power autonomy.

Vietnam can consider enhancing visibility of RTS through regulation on specifications/communication, implementing measurement, and enhancing forecasting of both demand and solar generation, so that the system operator can effectively operate the system, particularly in regions that are RTS rich.

At the same, it can consider planning RTS by province/regions, considering existing demand and grid. Ultimately, enabling greater visibility and coordinated control of RTS, small-scale batteries, and EV chargers could significantly reduce the requirement for investment in distribution network infrastructure, a particularly significant contribution to the cost of electricity supply.

It is recommended that the cost of distribution network investment be monitored, and that future PDPs take into account distribution network investment costs when developing future policies for distributed energy resources such as RTS, small-scale batteries and electric vehicles. In particular, the distribution networks should consider investing in utility-scale batteries in the distribution network to reduce net load at times of peak demand as an alternative to investing in distribution network in RTS rich locations. Both utility-scale batteries in the distribution network and behind-the-meter batteries should be considered as part of an overall least cost solution.

In the long run, Vietnam can test and demonstrate the feasibility of the virtual power plant concept to enhance value to both owners and the system operation, particularly when these systems are equipped with battery storage.

Recognising the reliability, resilience and economics of RE-based microgrids, and the significant cost associated with the maintenance and upkeep of Vietnam's massive transmission and distribution infrastructure; Vietnam should also undertake an economic assessment of the cost of maintaining the distribution system to remote, low density populations compared to the cost of removing the grid connection and installing stand-alone power systems as is being successfully implemented in Australia.

# FE–V

Future of Electricity
Viet Nam

A science – to – policy initiative
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