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Australian Energy Council

AUSTRALIA'S ELECTRICITY ARCHIPELAGO: THE CHALLENGES OF HIGH RENEWABLE GENERATION IN SMALL ISLAND GRIDS

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esaa

Executive Overview

Australia's electricity supply system reflects the geography of a large land mass and a relatively small, highly urbanised, coastal population. Most Australians are supplied electricity via two major grids, the National Electricity Market (NEM), covering the east coast and South Australia, and the South West Interconnected System (SWIS) supplying Perth and its surrounds. The rest of the continent is made up of an archipelago of more than 1000 small, islanded systems and micro-grids that supply electricity to around 450,000 people in remote and regional Australia.

The cost of supplying electricity to these small, remote electricity islands is higher than in urban grids because of their remoteness, size and reliance on higher cost sources of generation, in particular diesel. In theory, this is a logical gateway for the use of renewable energy generation technologies, to provide a more cost competitive solution to augment supply in these locations. The challenge for increased renewable penetration in these electricity islands is how to maintain appropriate quality and reliability of electricity supply.

Current experience to date across the archipelago confirms sporadic but increasing use of renewable energy technologies, in particular wind and solar PV. But where these technologies have been deployed at scale, they are often constrained by the ability of the host system to maintain stable voltage and frequency, particularly under certain conditions. Solving these challenges in small grids will be important to inform how we can increase renewable penetration in all networks.

High solar PV penetration rates, in particular, can lead to large fluctuations in voltage and frequency when solar output decreases and increases rapidly, as happens when some cloud patterns move across the sky. This requires standby generators to quickly increase/decrease supply if required. This can result in higher operating costs, or, at worst, compromised power quality. Power system frequency already fluctuates regularly with changes in demand, so there is already a level of variable load catered for in most island systems. The real challenge is when supply of intermittent renewable generation exacerbates these system management challenges, and adds to, rather than reduces, the instability of the system. This paper looks at three of the more advanced renewable integration case studies in Australian isolated grids.

- **King Island Renewable Energy Integration Project (KIREIP):** One of the leading edge examples of renewable energy integration is King Island, in Bass Strait. Since 1998 Hydro Tasmania has increased renewable generation to around 65 per cent of the island's total supply. This is at the global cutting edge of grid-scale renewable integration. King Island is a valuable demonstration of high levels of renewable integration and system support technologies,

- **Alice Springs:** With a relatively large proportion of solar PV generation for a small network, Alice Springs is a test-case for the impacts of increased solar in an island grid. There is already more than 4 MW of solar PV capacity in Alice Springs (around 15 per cent of average load), with several large-scale projects and many small systems on households. This will grow, with more than 3 MW set to be added over the next few years.

- **Carnarvon:** The difficulty of managing increasing penetration of solar PV in the isolated grid at Carnarvon in Western Australia has forced Horizon Power to limit new system installations. The network serving around 5,000 customers is reaching around 13 per cent of generation from solar PV, causing grid stability problems when there is passing cloud cover.

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Introduction

INTRODUCTION

Australia has two main electricity grids: 49 GW capacity National Electricity Market (NEM) and the 5.5 GW South West Interconnected System (SWIS). These networks cover the populated eastern and south-eastern coastline, including Tasmania (the NEM), and the south-west corner of Australia, around Perth (the SWIS). The remaining 85 per cent of the Australian continent is sparsely populated. There are around 450,000 Australians who live in remote and regional Australia. They are supplied electricity via an archipelago of more than 1000 island networks, micro-grids and stand-alone power systems for individual remote properties.

The largest of these island grids include the 1 GW North Western Interconnected System (NWIS) serving the resources sector operating in the Pilbara region, the Mt Isa Grid (454 MW) in western Queensland and the Darwin to Katherine Interconnected system (DKIS) (451 MW) in the Northern Territory. The smallest micro grids serve isolated homesteads and remote communities and often have a capacity of only a few kilowatts[1].

These island grids are geographically dispersed and diverse. They include many landlocked, arid regions with very high solar irradiation but more marginal wind assets, and islands like King and Flinders Islands in Bass Strait, with modest solar irradiation but significant wind resources. Most electricity islands in remote central and northern Australia share similar properties: (1) they are isolated, with higher (transport) costs to supply conventional fuels like diesel; (2) they have relatively high levels of solar irradiation but only limited wind energy resources; (3) high temperatures place a greater emphasis on the need for electricity (for cooling) and diminished value on cogenerated heat or waste heat resources. These conditions are shared by many islands and communities located across the equatorial and tropical regions of the world.

Table 1 – Capacity and percentage distribution of off-grid generation by region, 2011-12

Region	**Generation capacity by fuel type**						
	Natural Gas		Liquid Fuels		Renewables		Total
	MW	Share	MW	Share	MW	Share	
North West Integrated System (NWIS)	964	97.1%	29	2.9%	0.2	0.0%	993
Mt Isa	415	91.4%	39	8.6%	-	0.0%	454
Darwin-Katherine	409	90.6%	41	9.1%	0.1	0.0%	451
King Island	0	0.0%	6	67.4%	2.9	32.6%	8.9
Rest of off-grid WA	1,446	66.7%	676	31.2%	46.5	2.1%	2,169
Rest of off-grid Queensland	130	54.6%	107	45%	0.9	0.4%	238

Source: AECOM (2014), Hydro Tasmania

These smaller electricity island grids share similar operational challenges as larger systems, but with more constraints. They are required to manage their own varying load profile and periods of peak and low demand. With fewer generation facilities and no interconnection there are fewer options to solve supply constraints. These grids therefore can be seen as glimpses into the future to assess the impacts of new technologies and changed management system approaches to balancing energy supply and demand. At the smaller scale, some of these systems may be made up of solar photovoltaic (PV), a lead-acid battery and a diesel generator as a backup. It is entirely plausible that in sunny areas these systems could be relying on renewable generation for a significant share of their electricity generation.

While they are similar, each of these electricity islands is unique in its own way – different demand shapes, varying infrastructure and available renewable energy sources. In some of these grids, like Alice Springs, the cost of retail electricity prices and high output is

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[1] AECOM (2014), Australia's off-grid clean energy market research paper.

sufficient to encourage continued consumer uptake of rooftop solar PV systems. As with other parts of Australia, the combination of high up-front subsidies and falling costs of solar PV technology has meant sustained penetration in residential and increasingly commercial buildings.

Electricity grids evolved along the model of small numbers of large power plants sending electricity (one way) to customers. The rollout of distributed generation technologies like solar PV has meant that grids are now operating with increasing numbers of small generators (solar PV systems), distributed across the network with electricity flowing in multiple directions through the network. The effect of high solar and other renewable penetration rates in these isolated grids has been to amplify the challenge of maintaining quality of electricity supply as intermittent generation levels increase.

Solving power quality issues efficiently and reliably will be critical to the increased use of renewable energy technologies in electricity grids around the world. Small islanded grids are effectively a testing ground for systems and technologies to manage higher penetration of intermittent generation on a macro scale.

The esaa has reviewed the renewable integration projects occurring in King Island in Tasmania, Alice Springs in the Northern Territory, Carnarvon in Western Australia to compare and contrast the different experiences to date and what can be learnt from them.

SECTION I: IMPACTS OF INTERMITTENT WIND AND SOLAR

Renewable electricity generation technologies are being deployed and considered in off-grid locations for three primary reasons. First, they can reduce consumption of diesel and gas fuels used in conventional generation, and deliver ongoing cost savings. Second, they can reduce greenhouse gas emissions from electricity generation in these grids. Third, they can contribute to state and/or national schemes designed to increase renewable generation, in either national technology programs (Solar Cities), national subsidies for renewable generation (the Renewable Energy Target) or state-based feed-in-tariff schemes.

Australian remote grids are similar in operation in most respects to their larger counterparts. They comprise of a network of power lines and switching stations joining generation sources to customers. Because the same appliances and devices are used in all parts of Australia, the same system standards apply: these AC grids generate alternating current at 50 Hz, produced by synchronous generators in the grid, traditionally either diesel, gas or oil fuelled generators. All customers in the same AC grid receive power simultaneously at the same frequency.

Solar PV and wind are modular generation technologies that can operate with relatively similar efficiency in smaller or larger grids. Once operational, their operating costs are typically modest. For these reasons, they are considered well suited to remote grid applications, reducing generating costs overall on a short-run marginal cost basis. These savings are offset by (1) the upfront capital costs of installation, (2) variations in oil and gas prices and (3) the effects that increased intermittent supply has on plant cycling and ramp rates.

Increased penetration of wind and solar PV leads to increased cycling for existing plant and higher ramp rates as generators increase supply to make up for times when renewable output falls. A study from the US found that in a system with high penetration of solar energy (25 per cent solar and 8 per cent wind), production costs for existing fossil-fuel generators increase by 2.9-7.0 per cent as a result of higher cycling and ramping. While for a system with high quantities of wind generation (25 per cent wind and 8 per cent solar), these same production costs increase by 3.0-6.9 per cent.[2]

How micro-grids work

Micro-grids function in much the same way as larger grids, based around a small number of large generation units transmitting electricity to customers through a poles and wires distribution network. These grids have their own frequency and voltage control systems. Most Australian micro-grids have traditionally been powered by either gas, diesel or oil generators, fitted with governors and voltage control systems which match supply with the varying demand.

The recent introduction of distributed generation in these grids has also introduced the use of inverters, which convert the DC current from small scale renewable technologies into AC power. At low levels these technologies can displace demand on conventional generation and reduce fuel costs. But the conventional generator is needed to meet shortfall in supply and control frequency and voltage. Some inverters can provide voltage control.

It is possible to use a range of technologies to provide these services including some storage systems, regulating devices like static synchronous and VAR compensators and physical devices like flywheels which provide inertia at times when there is little or no generator inertia.

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[2] NREL et al. (2013). The Western Wind and Solar Integration Study Phase 2

Spinning reserve

Spinning reserve is generation capacity that is on-line but not providing electrical energy. It is used to compensate for sudden generation or transmission outages. Spinning reserves are the first response mechanism to manage grid stability when there are sudden variations in demand or supply. Because the level of electricity demand varies with time, enough spinning reserve in the system is required to maintain system stability.

Spinning reserve is required in large and small grids, whether or not there are renewables in the power system. As the percentage share of renewables increases, the volume of spinning reserve may be increased to maintain power system stability.

Where there is a high level of variable renewable energy (like wind or solar PV) the level of spinning reserve may need to increase. Increased spinning reserve requirements result in higher run-time and therefore higher maintenance for generation sets.

Ancillary services and small grids

All electricity systems, large and small, must constantly match demand and supply to ensure stable voltage and frequency. This is essential to maintain power quality and protect both the generators and appliances and motors used by customers. Given constant and sometimes sudden changes in the supply demand balance, there are a range of ancillary services which are needed to keep voltage and frequency within the system limits:

- **Regulation services**: involve making constant increases and decreases to power output. In small grids this has conventionally been provided by governors and voltage control systems attached to diesel or gas generators. Batteries and flywheel storage systems have already been used to provide regulation services in different grid systems across North America.

- **Contingency services**: provide for larger and possibly more sudden variations in demand-supply balance, mainly caused by a generator or load failure. Smaller grids can be at greater risk of supply losses because of the lack of alternative supply sources in these situations.

- **Intermittency**: is a major challenge in grids with increased deployment of solar PV systems, where supply from solar PV temporarily cuts in and out as a result of passing cloud cover. This can be more acute in small grids where solar makes up a higher share of supply.

- **Power quality**: or operational frequency management involves maintaining system frequency at a constant 50 Hz. This has conventionally been provided by larger power plants, assisted by the inertia both in the high speed spinning turbines as well as large electric motors on the demand side. This inertia in large grids helps power quality management by slowing changes to frequency in the event of sudden changes to supply or demand.

In smaller grids sudden shifts in the output of wind and particularly solar PV systems, or large shifts in the amount of power being used, can destabilise the frequency of the network. The impacts of these variations in renewable output can quickly be proportionally much larger than in larger electricity grids. In smaller systems like Alice Springs, Carnarvon or King Island, system frequency can vary over a considerably larger range. The normal operating frequency range on the Alice Springs network is 50Hz +/- 0.2 Hz. In certain situations (such as a generator failure) the frequency can vary quite significantly outside this range (for example, up to several Hz) very quickly.[3]

If the frequency does fall well below the normal operating level, load-shedding must occur to bring the system back into balance.

While variations in wind generation are more predictable, solar PV can have a greater impact on frequency management if operating at scale within a small network. If enough solar PV generation comes on-line or drops off-line over a very short period, then there is the

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[3] Hancock, M. (2011) 'Alice Springs: A Case Study of Increasing Levels of PV Penetration in an Electricity Supply System'. Report for the Australian PV Association.

potential for the frequency to rise too high or fall too low. This can lead to a variety of problems from minor (flickering lights), to moderate (damage to equipment), to major (shutting down the power system).

Intermittency of wind and solar PV

Electricity systems are built with variability in mind. As demand for electricity changes, power systems must adapt to this by changing the amount of generation required. Short-term changes in load (over seconds or minutes) tend to be minor and are the result of random events that can increase or decrease demand. Over periods of several hours, changes in load tend to be more predictable. For example, demand tends to peak in the morning and evening when people are at home. Demand on weekends is lower as some businesses are closed.

The key issue for renewables is that these changes in demand are better understood and more predictable than the output of solar and wind generation. The electricity production of an individual wind turbine or solar installation can be highly variable. The aggregate variability of multiple turbines at a single site or solar installations in a small area is significantly less variable (see page 14-15).

For large-scale wind power, the variability over seconds or minutes is generally small, but over several hours, can be quite large. In systems with large volumes of wind generation, a fall in wind output can increase wholesale energy prices.[4] In Australia, the Australian Energy Market Operator has developed the Australian Wind Energy Forecasting System (AWEFS) to provide better forecasts of wind generation over a series of short-term and long-term timeframes.[5]

Solar PV systems both reduce the load customers draw from the network and also feed power back into the network. Exporting power can result in higher line voltages than would occur without PV systems. Solar output changes rapidly when sunlight onto solar panels is blocked or impeded, primarily by cloud cover. This results in changes to system voltage. Voltage changes in a similar way when the load changes. For example, a number of customers turning on air conditioners or pool pumps can have much the same effect as solar PV systems increasing or decreasing output suddenly. As PV penetration levels on a network increase, there is a risk that system voltage limits may be exceeded; this is also a risk where customer loads significantly increase or decrease. For that reason, it is important to recognise whether the impact of solar PV is the same, greater or lower than existing network risks.

Government-owned grids and the “death spiral”

A curious feature of the supply of electricity in Australia’s electricity archipelago is that almost all of it is government owned or controlled. This contrasts with the National Electricity Market (NEM), which is evolving to a fully deregulated and privatised model, consistent with mature electricity markets around the world.

Two notable recent features of electricity supply costs in Australia have been (1) government owners of energy utilities continued desire to socialise the costs of supplying electricity to remote and regional communities by various cost transfers onto their broader urban customer base, and (2) the risk of a ‘death spiral’ for electricity grids, where increased distributed generation (rooftop solar PV) transfers higher network costs onto non-solar PV customers, incentivising them to invest in solar PV. This leaves fewer and fewer customers paying an increased share of the fixed cost of the network.

Increased renewable generation in remote island grids can deliver net benefits to all consumers (and owners) if it can reduce local operating costs greater than the cost of the new supply. The principal benefit is realised in avoided fuel costs, while the principal cost of renewables is the up-front capital costs and the changes in cost of maintaining quality and reliability of supply. This cost-benefit will be positively impacted in the future by meaningful constraints/pricing on greenhouse emissions.

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[4] Priftakis, P. (2015), ‘On a high: SA renewables and wholesale prices’, *Energy Supply Association of Australia*.
[5] Australian Energy Market Operator, Australian Wind Energy Forecasting System.

Currently the costs and benefits are masked to local consumers by equalisation measures imposed by government owners. Evolution of these measures to reward efficient improvements in regional grids (of all kinds) would be an important step in facilitating continuous improvement in all of Australia's electricity grids.

The potential role of storage in micro-grids

Electricity is often described as the most volatile commodity in the world because of the absence of large scale, cost effective storage. There are a wide range of different physical and chemical storage technologies for electricity, but they have been constrained in most grids by cost and/or availability (i.e. limited access to pumped storage systems). Recently there has been accelerated interest and investment in developing improved and cheaper storage technologies, particularly to complement the intermittent nature of leading renewable technologies like solar and wind. Clearly, developing cost effective and ubiquitous storage systems would be almost as transformative as the invention of electricity itself.

The value of storage is only amplified in small and remote grids, particularly if it can both store and release electricity and augment systems management. For practical purposes most discussion in this regard in relation to remote grids in Australia has centred around the use of electrochemical batteries. Batteries are used in the supply of electricity to small (often single dwelling) off-grid systems in remote Australia, where the relative costs of these systems is cheaper than the cost of grid connection and the portability and low maintenance costs of the battery is highly desirable.

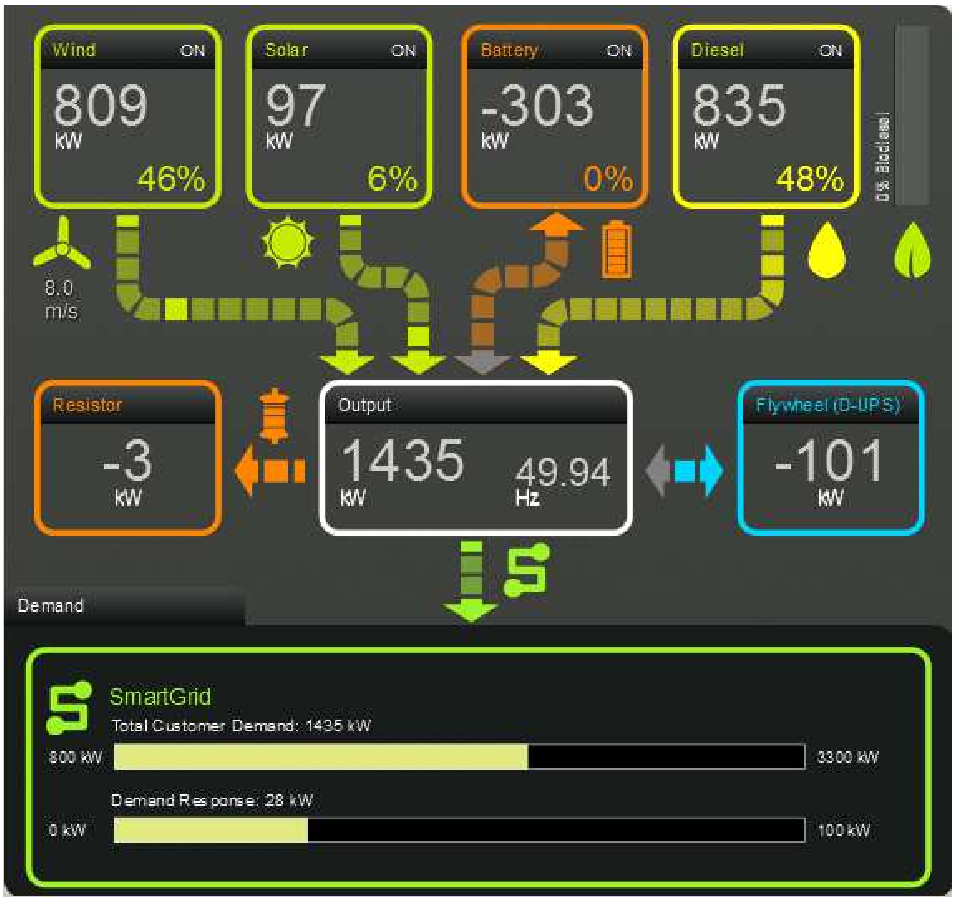
Batteries and supporting control systems and controllable inverters can be set up to provide different balancing services, and are already performing these services in some applications around the world. The challenge for storage technologies and applications in small grids is the relative cost of storage technology and how this may evolve over time.

SECTION II: CASE STUDIES

1. King Island

King Island, in Bass Strait, has a population of around 1,600 people and an internationally recognised cheese factory.[6] Until 1998 the Island was powered by four 1.2 MW diesel generators. Since 1998 the small electricity grid on the island has evolved significantly through the implementation of Hydro Tasmania's $18.25 million King Island Renewable Energy Integration Project (KIREIP). The KIREIP has been testing large-scale solar and wind generation in a small island grid. The project is designed to reduce the island's dependence on diesel for power generation, by increasing the use of renewable energy, while also maintaining a reliable and stable electricity supply. The ambition of the project is to reduce costs and greenhouse gas emissions. It is to date the only megawatt-scale hybrid system in the world able to achieve 100 per cent renewable penetration, or 'diesel-off' operation.

Figure 1: Snapshot of King Island's electricity supply at 11.36am, Friday 4 September 2015



Total Customer Demand: 1435 kW

Demand Response: 28 kW

In 1998, Hydro Tasmania commissioned three wind turbines at Huxley Hill on King Island. The three turbines were rated at 250 kW each, providing a total renewable energy capacity of 750 kW. In 2003, the wind farm was expanded with the addition of two 850 kW turbines taking the total capacity to 2.45 MW.

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[6] Australian Bureau of Statistics, King Island. Last Accessed 18 September 2015.

As part of the expansion of the Huxley Hill wind farm, Hydro Tasmania installed a Vanadium Redox Battery (VRB) energy storage system on the island in 2003. The objective of the storage system was to allow for a greater contribution of wind power on the island to displace diesel generation. Although the system was leading edge technology at the time, it failed after a relatively short life. Investigation into restoring the VRB concluded it was not economically viable to restore and was decommissioned. A new electrochemical battery system has since been installed, capable of 3 MW of power contribution and storing 1.6 MWh of useable energy.

KIREIP is targeting 65 per cent of the annual energy demand to be met by renewable energy sources, with the remaining power produced by diesel generation (although there are plans to replace diesel with biofuels). In 2014-15 renewables contributed 40 per cent of King Island's power, representing an annual diesel saving of approximately $2 million.[7] The cost per kWh for this advanced supply system is not publicly disclosed by Hydro Tasmania.

At times, particularly when it is very windy, the island can already be powered by 100 per cent renewable energy. Since early 2014, the system has achieved more than 1,500 hours of total 'diesel-off' operation, including a record of 46 straight hours reached in November 2015.[8] This is among the most advanced integration of grid scale renewable energy in the world.

King Island currently has the 6 MW diesel-powered Currie Power Station, 2.45 MW of wind capacity and around 450 kW of solar PV to power the island. The KIRIEP uses these facilities, as well as biodiesel and enabling technologies, such as battery storage, smart grid technology, demand response and flywheels to maximise the possible contribution from renewable energy.

The KIREIP is an advanced research and development project which has the potential to help other off-grid communities to understand how renewable sources and enabling technology can provide reliable renewable generation.

2. Alice Springs

Alice Springs is located in the geographic centre of the Australian continent. The Alice Springs electricity grid serves around 26,000 people in the town and surrounding communities. Alice Springs enjoys more than 300 cloudless days each year, and has a mostly warm, arid climate. The primary sources of thermal generation are three gas and gas/diesel generators: Owen Springs, Brewer Estate and Ron Goodin power stations. Table 2 shows details on the size and type of these stations.

Table 2 – Thermal power stations in Alice Springs

Power station	Fuel type	Capacity
Brewer Estate	Gas	8.7 MW
Owen Springs	Gas	32.1 MW
Ron Goodin	Gas and diesel	44.6 MW

The load profile of the Alice Springs grid is also very similar to that of the east coast states of Australia. Peak demand reaches as much as 55 MW on hot summer afternoons, as air conditioners get turned on/up when consumers arrive home (see Figure 2).[9] In winter, load can fall to as little as 18 MW during the day in winter. Winter peaks are smaller but the system still sees a peak of around 40 MW in the morning, followed by a lower evening peak (see Figure 3).[10] This is relatively typical of larger grids around Australia.

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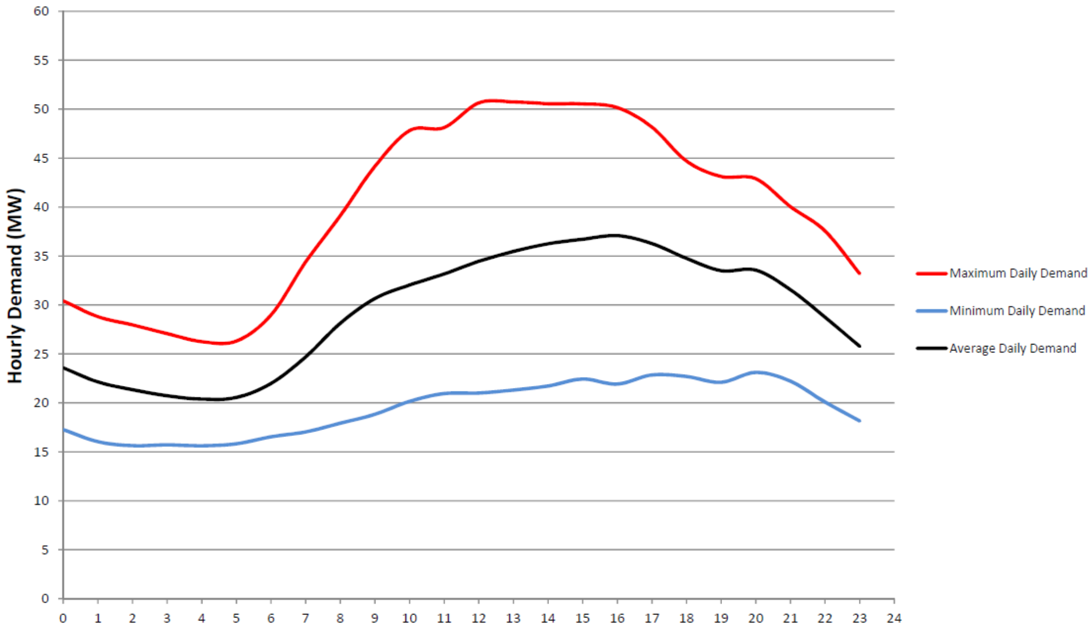
[7] Hydro Tasmana, pers. comm.

[8] Hydro Tasmania, 'Round the clock milestone for renewable energy,' 11 November 2015.

[9] Hancock, M. (2011) op cit.

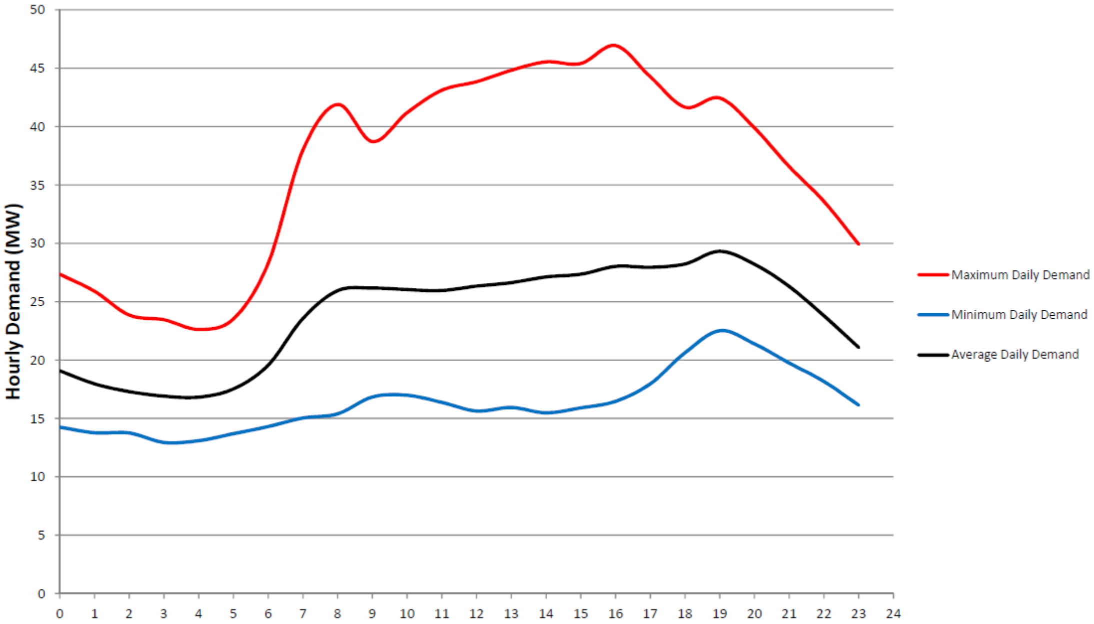
[10] CAT Projects, (2015). 'Investigating the Impact of Solar Variability on Grid Stability'.

Figure 2 – Alice Springs demand curve, Summer



Source: Power and Water Corporation

Figure 3 – Alice Springs demand curve, Winter



Source: Power and Water Corporation

Peak demand in the Alice Springs system correlates with the maximum summer temperature in the town. Power and Water Corporation (PWC), which manages the electricity network, forecasts small growth in maximum demand in Alice Springs of 0.3 per cent per year. These forecasts factor in the impact of increasing levels of (mostly rooftop) solar PV.[11]

Solar PV

Alice Springs also has, like many parts of Australia, significant penetration of both utility scale and rooftop solar PV capacity. This was accelerated by it being one of the locations for the Australian Government's Solar Cities Program. This program was introduced by the Federal Government in 2004 as a pilot program to trial solar PV in selected communities around Australia. As part of this program, which was expanded to Alice Springs in 2008, several commercial-scale 'iconic' solar PV systems were installed across Alice Springs as well as more than 300 solar photovoltaic (PV) systems that were installed on homes and businesses.[12] These iconic installations showcased different types of solar technologies.

In addition to these systems, a 325 kW flat plate solar PV system was installed at the Alice Springs Airport in 2014.[13] The panels double as shading for cars at the airport's long-term car park. The Alice Springs grid was connected to a micro-grid at nearby Hermannsburg (130 km south-west of Alice Springs) in 2014. This connected a 192 kW concentrating PV system at Ntaria, to the Alice Springs grid. Table 3 sets out the details of major solar installations in Alice Springs.

Table 3 – Large-scale Solar PV installations in Alice Springs[14]

Project	Technology	Capacity
Crowne Plaza	Flat plate PV	305 kW
Alice Springs Airport	Dual-axis tracking concentrating PV	235 kW
Alice Springs Airport long term car park	Flat plate PV	325 kW
Uterne Solar Power Station	Single-axis tracking flat plate PV	4.1 MW
Alice Springs Aquatic and Leisure Centre	Black pipe solar water heating	1700 m2 (3450 GJ offset)
Araluen Cultural Precinct	Flat plate PV	180 kW

The first stage of the Uterne Solar Power Station (Figure 4) was installed in 2011, adding 1 MW of capacity to the Alice Springs grid. This was upgraded to 4.1 MW in 2015.[15] The Alice Springs Airport also plans to double the size of its long-term car park solar PV system to 650 kW in 2015.[16]

Including the original 300 households taking part in the Solar Cities program, a more than 1,250 households and businesses have installed solar PV systems on their rooftops. There is currently around 5.5 MW of small-scale, rooftop PV in the Alice Springs grid.[17] In total there is currently around 10.6 MW of solar PV capacity in Alice Springs.

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[11] Power and Water Corporation, (2015), 'Network Management Plan 2013/14 to 2017/18'.
[12] Alice Springs Solar City, Iconic Projects. Accessed 8 April 2015.
[13] Alice Springs Airport, 'Solar Power Station and undercover parking now available,' 16 May 2014.
[14] Alice Springs Solar City, Iconic Projects. Accessed 8 April 2015.
[15] Epuron, Uterne Solar. Last accessed 18 September 2015.
[16] Alice Springs Airport, 'Alice Springs Airport to source bulk of its power from the sun,' 14 August 2015.
[17] Clean Energy Regulator, Postcode data for small-scale installations, 0870 postcode, Data as of 31 October 2015.

Figure 4 – Uterne Solar Power Station

The impact of solar PV on the Alice Springs grid

Territory Generation is the generator operating the power stations in Alice Springs. Territory Generation has observed that, as a result of the high level of PV in the Alice Springs network, the spinning reserve has increased to 8 MW during the day. This falls to 5 MW overnight, meaning that the net impact of the increased installation of solar PV solar is a 3 MW increase in spinning reserve.

During 2010 there were several system frequency 'drop' events reported in the Alice Springs network during the day when there was significant solar PV generation. These events saw the grid frequency fall below 49.9 Hz. The trigger for these events was one of the three generators tripping off the system temporarily because of unplanned technical issues.

As a result of the unplanned reduction in generation, grid frequency fell below 49.9 Hz. Territory Generation expected demand to fall as a result of this event, with the fall in frequency triggering load shedding from major demand sources,. Curiously, the opposite occurred. Demand *increased* by around 1 MW before gradually reducing once the system frequency had returned above 49.9Hz.[18]

After investigating the events, Territory Generation concluded that the sudden rise in demand was due to the PV systems on the network dropping out once the system frequency fell below the PV inverters' low frequency trip setting of 49.9Hz. In effect, this meant that instead of these rooftop solar systems exporting electrons and displacing residential demand, the switch off of the solar inverters meant these consumers began importing electrons, increasing demand on the grid. The solar PV system inverters connected to the Alice Springs network up until that time had been programmed with default frequency trip settings of 50Hz +/- 0.1Hz to bring them in line with European grid-connection requirements.

To resolve this issue, Territory Generation decided to change the frequency trip settings to 50Hz +/- 4Hz. While these settings could be applied to future installations, the practicality of changing existing inverters across hundreds of residential and commercial buildings is

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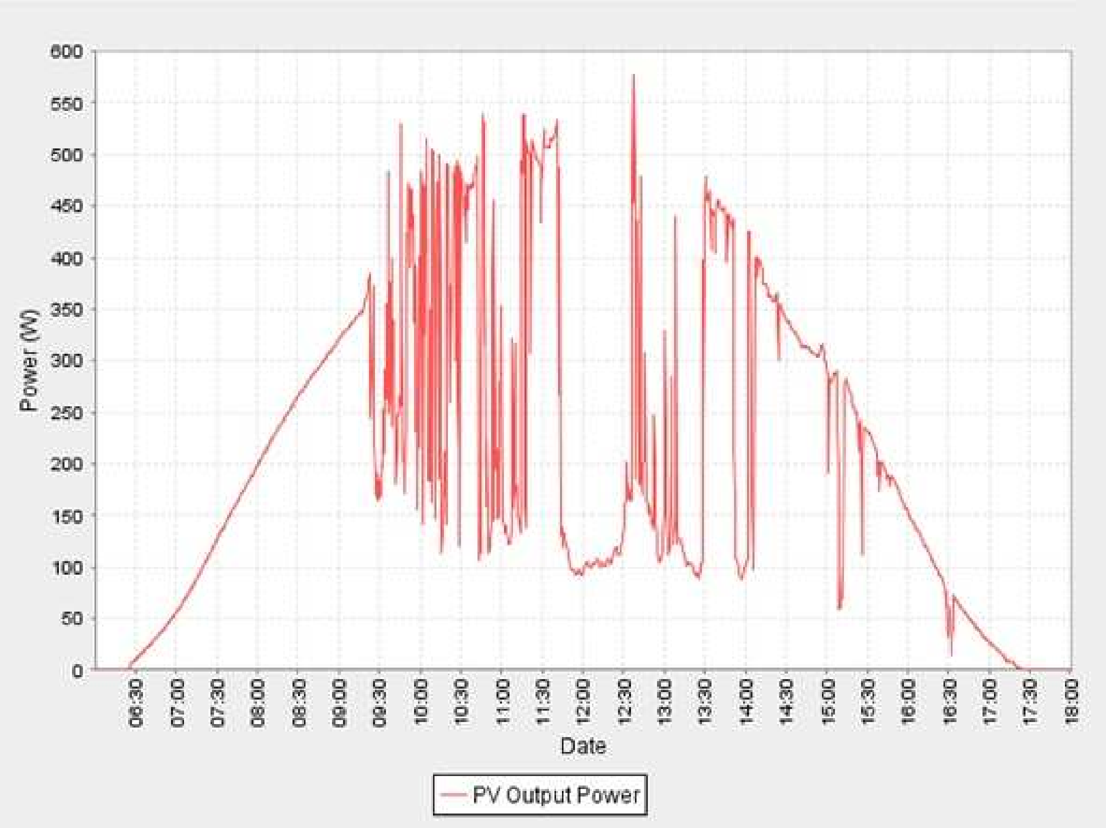
[18] Hancock, M. (2011), op cit.

challenging. By contrast, systems installed under the Solar Cities Program could be progressively changed when PV installers performed the 12-monthly service inspections of the PV systems.

Residential solar PV systems in Alice Springs now face a cap of 4.5 kW of capacity. Systems larger than this need further approvals and may face limits to the amount of electricity they can export to the grid. Commercial systems also face size limits (expressed in kVA) and require the use of export limiting devices which ensure that PV systems only generate as much power as the user requires and does not generate excess energy.[19]

Several stakeholders in Alice Springs also raised concerns about the impacts of the intermittent nature of solar PV, in particular, at the 4.1 MW Uterne solar power station. A recent study on solar systems in the Northern Territory found that "clouds can reduce solar output by up to 80 per cent in six seconds."[20] Figure 5 shows what solar output can look like for a small PV system (less than 1 kW capacity) on a day of high intermittency in Alice Springs. A larger system may not see such extreme changes in output.

Figure 5 – Alice Springs solar PV load profile on a typical day, with an intermittent output of solar radiation



Source: CSIRO

An investigation by the Northern Territory Utilities Commission examined the variability of output at Uterne and how this affected the rest of the Alice Springs system. It found that "while the magnitude of variation is within the regulation capacity of the Ron Goodin and Owen Springs Power Station units the volatility can be managed."[21] Before the expansion of the Uterne Power Station to 4.1 MW, the NT Utilities Commission argued that "further expansion of (Uterne) will require consideration of regulation reserves."[22] It also indicated

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[19] Power and Water Corporation, PV Class Requirements.

[20] Power and Water Corporation, (2014). 'Solar/Diesel mini-grid handbook'.

[21] NT Utilities Commission, 2012-13 Annual Report. p 101.

[22] Ibid.

that "If similar volatility was displayed by domestic PV installations at any scale this may accelerate the rate at which it begins to impact on PWC operations and potentially network security or at least network frequency regulation."[23]

Figure 6 – Alice Springs Airport solar tracking plant

Source: Alice Springs Airport

Is distributed solar more stable than utility solar?

Alice Springs has also been the test-site for research into the different impacts of solar PV systems on grid stability. CAT Projects is an Alice Springs-based engineering consultancy, which provides engineering services and advice on energy and infrastructure projects. Their focus is on projects in remote areas. With financial assistance from the Australian Renewable Energy Agency (ARENA), CAT Projects recently investigated the impact of variable solar PV output on grid stability in Alice Springs.[24]

Its 2015 report found that solar PV capacity could be increased without major changes to grid variability. Using a network of solar monitoring stations the project developed an improved estimate for the maximum number of solar power generators that can be connected to the electricity grid without energy storage, taking into account the generators' distribution across the geographical area of the grid.

The report argued that the assumption that grids are inherently stable is false. The Alice Springs grid "encounters a significant level of load variance as part of normal operation".[25] CAT Projects' research claimed that the variability associated with a solar plant undergoing a high degree of intermittency is close to the normal level of variability in the load profile.

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[23] ibid.

[24] CAT Projects, (2015). 'Investigating the Impact of Solar Variability on Grid Stability'.

[25] Ibid. p 3.

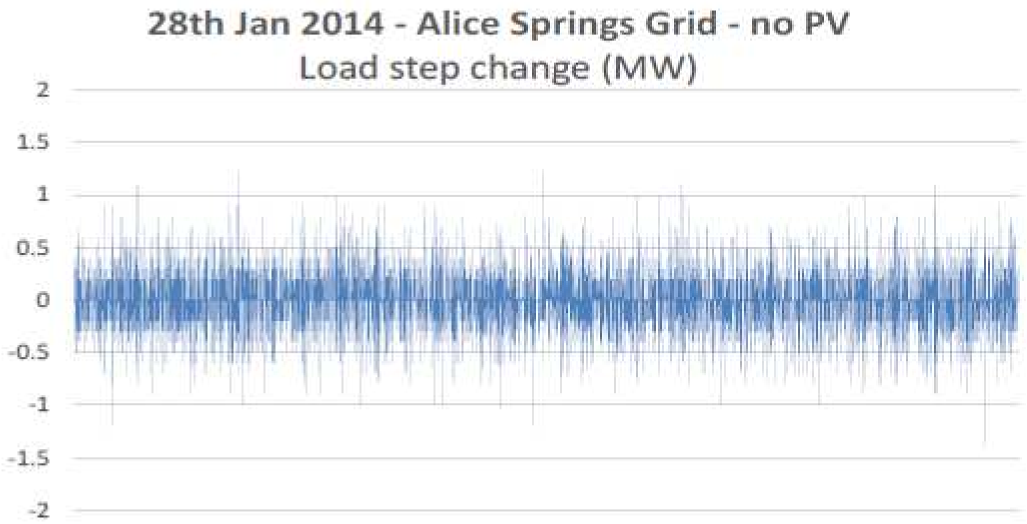
CAT Projects also examined the impact of adding an additional 10 MW of solar into the Alice Springs grid. It found that variability would be reduced if the additional solar was distributed geographically in the grid rather than in one location (e.g. nine 1.1 MW systems rather than one 10 MW system).

The results of this study suggest that increased geographical distribution of PV systems could allow for solar PV "potentially exceeding 60% of demand, into existing networks without disrupting the underlying variance that normally exists in grids".[26] CAT Projects found that a distributed solar PV array produces similar levels of intermittency to that which already exists in the load profile.

There are limits to the conclusions in the study. As acknowledged in the report, the conclusions are in the context of the entire network and power system. There may be local areas of the networks where solar PV installations are not appropriate due to other grid constraints including voltage rise and frequency variability. This study did not examine these power quality areas. The study also focussed on utility-scale solar PV rather than also considering the impact of distributed, small-scale solar PV. Future research on the effects of high penetration of solar PV on voltage and frequency will be important to improve understanding of how electricity systems can manage increasing levels of solar energy.

Figure 7, below, shows the existing variability in the Alice Springs electricity network on a cloudy, summer day, with no additional solar PV. As can be seen, the load is constantly changing over 15 second periods.

Figure 7 – Step changes inherent in the Alice Springs grid with no additional PV included (15 second intervals over 24 hours)



CAT Projects investigated how this variability would change if a 10 MW solar PV plant were added to the network. Figure 8 shows that the variability increases markedly during the middle of the day as large amounts of solar power are added and removed from the system as a result of clouds passing overhead,

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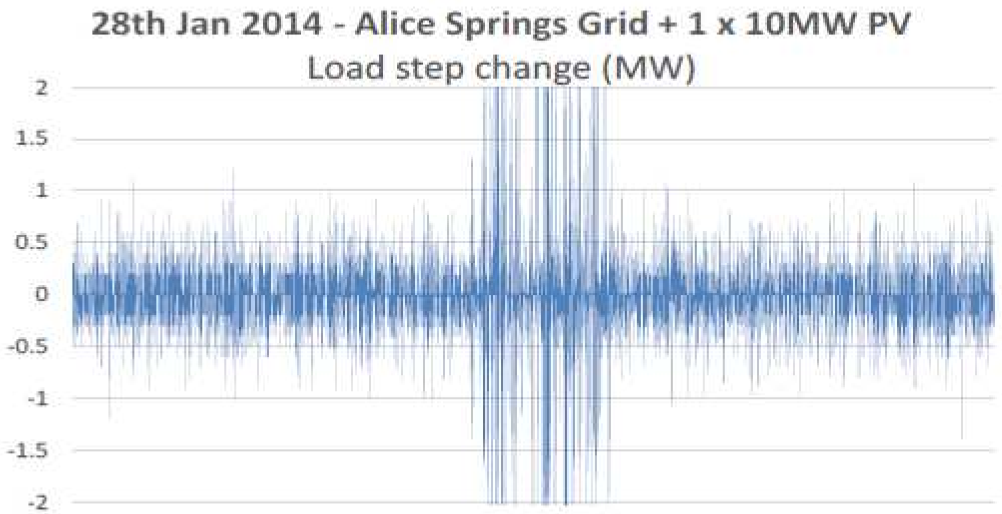
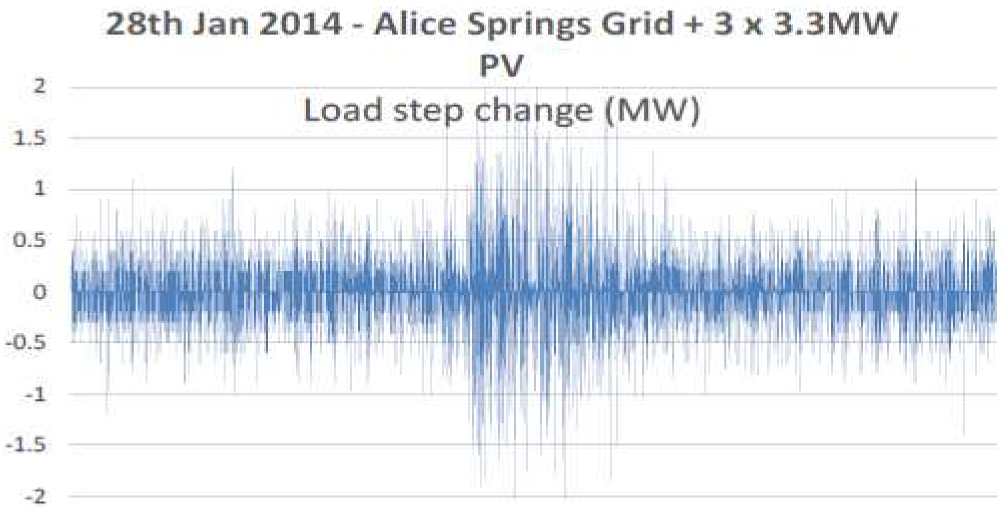
[26] Ibid. p 9.

Figure 8 – Step changes in the Alice Springs grid with the addition of a simulated 10MW centrally located PV plant (15 second intervals over 24 hours)



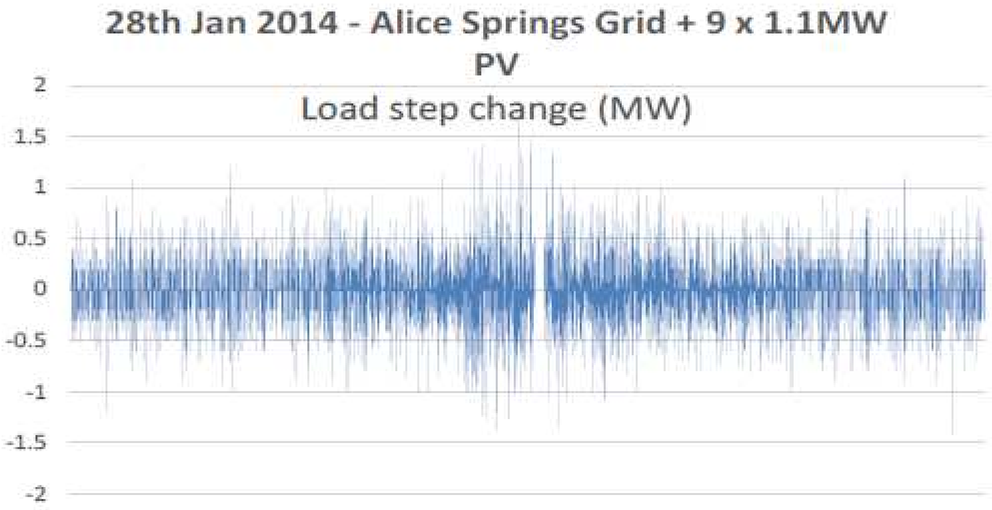
This variability could be reduced if the same amount of solar energy were being produced by three 3.3 MW plants distributed geographically around Alice Springs rather than at one large solar power station. Figure 9 shows how this variability is reduced, though it is still higher than the base case (as seen in Figure 7).

Figure 9 – Step changes in the Alice Springs grid with the addition of three simulated geographically dispersed 3.3MW PV plants (15 second intervals over 24 hours)



The variability can be reduced further still if the additional 10 MW of PV were provided by nine 1.1 MW PV plants dispersed across the Alice Springs area. As can be seen in Figure 10, there is little difference between this scenario and one with no additional solar PV.

Figure 10 – Step changes in the Alice Springs grid with the addition of nine simulated geographically dispersed 1.1MW PV plants (15 second intervals over 24 hours)



3. Carnarvon

Remote northern Western Australia hosts numerous isolated electricity systems of varying size. Horizon Power operates many of these small electricity systems and, like in other parts of Australia, is having to adjust to the influx of residential solar PV systems. While the cost of supplying electricity can be quite high in some of these remote systems, households in regional WA pay the same retail prices as those in the large South-West Interconnected System (SWIS), due to the long standing electricity price equalisation policies of the WA Government. Even at these subsidised prices, solar PV is seen as an attractive proposition for many remote and regional customers, as it is for customers in the major grid in Australia.

In some of the smaller and most remote micro-grids operated by Horizon Power, they seek to actively encourage residential uptake of rooftop solar PV by providing generous premium, net feed-in tariffs (up to $0.50/kWh). This is cost effective because it offsets the high cost of delivered diesel fuel to these regions.

Carnarvon is a small town located around 900 kilometres north of Perth. It has a population of around 5,000 people, and its major industries include fishing, tourism, mining and agriculture. Horizon Power operates a 17MW gas and diesel generator supporting a micro grid which supplies the town and its surrounds, and supported by a 290kW solar farm built by EMC Solar in 2012.

There are also more than 120 solar PV installations totalling 1.3 MW of capacity. This is inside a small network supplying an average load of 8 MW in summer, 7 MW in winter and with a peak load of 11 MW. Load can drop as low as 4.5 MW in winter. In 2012, it was estimated that at midday, solar PV was providing 13 per cent of total power supply.[27]

As a result of these levels of solar PV penetration, in 2013 Horizon Power announced a freeze on all new solar PV installations to avoid increased system management challenges. As with other micro-grids with high PV penetration, the main system management issues occur when clouds pass overhead and impact solar PV output. Horizon Power indicated that the ramp rate required to meet this variation in load was not possible with the existing generators.

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[27] Australian PV Association (2012), 'Carnarvon: A Case Study of Increasing Levels of Solar PV Penetration in an Isolated Electricity Supply System'

As a result, Horizon Power has adopted limits on the capacity of solar PV that can be installed in each of its systems and different rules depending on the capacity of the system.[28] Systems are split into three categories: less than 5kW capacity, 5-50kW, and 50kW-1MW. If the limit on solar PV capacity has not been reached, systems below 5kW can continue to be installed without the need for generation management. More capacity can be installed with energy management systems that smooth out the supply of the solar system. This can include demand management and battery storage technology. All systems larger than 5kW must have energy storage attached to smooth out the supply of energy back to the grid. Customers with systems larger than 50kW, and in rare cases, systems larger than 5kW, must also allow Horizon Power to curtail the renewable energy installation's generation output to prevent system instability. For the most part, these management systems are too expensive for households to install but can be a worthwhile investment for larger solar PV systems for businesses.

In addition to the problem of ramp rates, Horizon indicated the other problem associated with high penetration of solar PV was reaching low levels of load that strained the capabilities of existing generators. This typically occurred on sunny, cool days with naturally low levels of load – Sunday and public holidays.

In November 2015 Horizon Power announced a trial involving two 1 MW batteries in Carnarvon to help manage the impact of the high penetration of solar PV. The two batteries will be installed at the 17 MW Mungallah Power Station and will be used to enhance generating capacity and optimise spinning reserve. The aim of the project is to determine whether battery storage can provide a cheaper spinning reserve option than the current use of diesel.[29]

SECTION III: FINDINGS

It is clear that high penetration rates of solar PV can have an impact on small grids. While this appears to be relatively benign at present, the dynamics that are making solar PV more economic means any existing problems are likely to be exacerbated as solar PV levels increase. This may increase costs in the long-term. Options to limit any detrimental impact of solar PV also need to be tailored to the scale of the technology causing the problem: small- or utility-scale.

1. Utility-scale solar

One potential solution to managing intermittency could be to allow greater discretion to the network operator to curtail utility-scale solar power generation on days of high intermittency. A CSIRO study into the intermittency of solar found that one way to manage that factor is to "control the solar generation output under intermittent cloud coverage during periods of peak system demand when the network has fewer generating units on standby and less on-line regulating capacity".[30]

In towns like Alice Springs, where there is a high number of clear days, there should be relatively few days when curtailing solar PV production is necessary. In other areas this could be more regular. Regardless, it is important that if this is to occur, a transparent methodology to justify how and when curtailment occurs is developed to ensure that the interests of solar PV plant operators, power system operators and consumers are supported.

Research from Alice Springs-based CAT Projects found that spacing out solar installations geographically can help to limit the variability on days when intermittency becomes a problem. From the perspective of the electricity network, the location of a solar PV station could make a difference to the impact this intermittency can have on network constraints. This backs up a similar conclusion from a study in Hawaii which found that "if the solar PV resources are concentrated into larger plants with single-axis tracking rather than geographically dispersed with no tracking, the system will require more operating reserves to respond to the additional short-term variability in power output".[31]

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[28] Details on the available managed and unmanaged solar capacity and feed-in tariffs by area is available at Horizon Power's website.

[29] WA Government, 'Battery trial leads the way for renewable future,' 24 November 2015.

[30] CSIRO (2012). 'Solar intermittency: Australia's clean energy challenge'. p 173.

[31] National Renewable Energy Laboratory (2013). 'Hawaii Solar Integration Study: Executive Summary', p 18.

As such, decisions on future investments in large-scale solar should involve power system operators to ensure that the solar is appropriately sited to minimise the risk of a geographic concentration of solar PV, that could result in constraints on the network or a higher risk of unacceptable levels of intermittency. It is crucial that stakeholders work together to find ways to incorporate increasing levels of solar PV into the grid without increasing the risks to security of supply and costs to consumers.

The introduction of deep connection charges may also be necessary in order to ensure that future utility-scale solar plants are sited in areas that do not require costly upgrades to the grid, or that project developers contribute to the cost of upgrading the network.

2. Small-scale solar

For households with small-scale PV systems, one of the critical areas of improvement for overall system stability is to remove cross subsidies and move towards cost-reflective tariffs. Households, irrespective of whether or not they have solar PV, with high levels of peak demand, which contribute to the need for network upgrades should face prices that more accurately reflect the cost they impose on the network.

In many small grids there is a community service obligation (CSO) that helps keep electricity prices at the same level as for households in more densely populated areas. CSOs can still be supported as part of a shift to cost-reflective tariffs.

Alice Springs has already resolved one of the problems associated with high penetration of small-scale solar PV by adjusting the trip settings of inverters (see page 12). In other small grids it will be important to ensure that there is enough scope in inverter settings to ensure that a change in system frequency does not result in solar PV systems shutting off suddenly.

Acknowledgements

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