Alice Springs

A Case Study of Increasing Levels of PV Penetration in an Electricity Supply System

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- CAT Projects:
    - Lyndon Frearson, General Manager.
- Alice Solar City Project:
    - Brian Elmer, General Manager.
    - Sam Latz, Commercial Services Manager.
    - Chris Penna, Monitoring and Evaluation Manager.
- Agnew Solar:
    - Ben Frichot, Northern Territory Manager.

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Alice Solar City Project and CAT Projects are also acknowledged and thanked for their permission to use photos of various Alice Springs PV systems in this report.

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1 EXECUTIVE SUMMARY

The Case Study

This report presents a case study of one example of an Australian electricity grid with increasing levels of photovoltaic (PV) power system penetration. The grid considered is the electricity supply system for the Alice Springs township in the Northern Territory, Australia, which is owned and operated by the Northern Territory Power and Water Corporation (P&W).

The case study has been undertaken as part of a broader Australian research project titled "*Support for Australian participation in an international RD&D collaboration on Photovoltaics – IEA PVPS Task 14: High Penetration of Photovoltaic systems in electricity grids".* This project is being co-ordinated by the Australian Photovoltaic Association (APVA) in conjunction with the Centre for Energy and Environmental Markets (CEEM) at the University of New South Wales, and with funding from the Australian Solar Institute (ASI).

The broad aims of the overarching research project are to:

- enhance understanding of the technical, economic and regulatory requirements needed to achieve high levels of PV penetration in electricity grids in Australia; and
- support Australia's active participation in the International Energy Agency's Photovoltaic Power Systems Program Task 14 (IEA PVPS Task 14) which provides a forum for all IEA countries to share knowledge and experiences on the integration of high levels of PV into electricity grids.

The specific objectives of the case study are to identify and communicate P&W's key experiences to date with increasing levels of PV penetration on the Alice Springs electricity supply system, from a technical perspective, and to identify areas that may require further investigation and/or study.

The case study is also intended to be made available to an international audience through the IEA PVPS Task 14 program.

Alice Springs

Alice Springs is a township of approximately 30,000 people in the Northern Territory, Australia. Situated in the centre of Australia and approximately 450km from Uluru (or Ayers Rock) it is also a popular tourist destination. It has a primarily sunny and arid climate and, being located on the Tropic of Capricorn, possesses an excellent solar energy resource. It has an average of 200 clear days per year and 9.6 sunshine hours per day giving an average daily solar exposure of 22.3 MJ/m^2, very high by both Australian and World standards.

The Alice Springs Electricity Network

The Northern Territory Power and Water Corporation (P&W) is responsible for the provision of electricity and water to customers throughout the Northern Territory, including Alice Springs. P&W owns and operates the Alice Springs electricity supply system which is an isolated network supplying the Alice township as well as a small number of outlying rural properties.

The Alice power system has three main centralised power stations incorporating nineteen dual-fuel gas/diesel generators with a combined generation capacity of approximately 100 MW. Natural gas is supplied to Alice Springs and the power stations from nearby natural gas fields and also via a pipeline from Darwin, whereas diesel fuel is trucked in. These power stations are connected to a high voltage sub-transmission and distribution network which feeds power to and throughout the Alice township and the outlying areas. The only distributed generation systems on the network are photovoltaic (PV) power systems, these having increased in number and capacity significantly over the last three years.

The network load demand is seasonal in character, being influenced heavily by cooling loads in summer and heating loads in winter. The system peak load occurs on summer afternoons and is presently around 55MW, while the minimum load typically occurs after midnight on non-summer evenings and is presently around 15MW. The average load in 2010 was 26MW.

PV Systems Connected to the Network

Prior to 2008 there were only two small residential PV systems connected to the Alice network. There are now 528 systems connected with a combined capacity of 2.1MWp, with another 1MWp system (Uterne) due to be connected in July this year which will bring the total installed peak capacity to 3.1MWp. The table below provides a summary of the PV systems on the Alice network.

Category	#	Capacity (kWp)	% Inst. Cap	% Inst. + Pend. Cap	Comments
Residential Systems					
Installed under ASC program	277	530	25%	17%	Mostly 2kW (some 1 & 1.5kW)
Installed outside ASC program	183	464	22%	15%	1.5kW to 5kW systems
Total Residential	**460**	**994**	**47%**	**32%**	
Commercial Systems					3kW to 40kW systems
Installed under ASC program	35	367	17%	11.8%	
Installed outside ASC program	4	14	1%	0.5%	
Total Commercial	**39**	**381**	**18%**	**12%**	
Iconic/Showcase Systems					
Desert Knowledge Solar Centre	27	220	10%	7%	Showcase (2008)
Crowne Plaza Hotel	1	305	14%	10%	ASC Iconic (early 2009)
Alice Springs Airport	1	235	11%	8%	ASC Iconic (Nov 2010)
Total Installed Iconic/Showcase	**29**	**760**	**36%**	**24%**	
Uterne Solar System (pending)	*1*	*969*	*45%*	*31%*	*ASC Iconic - due July 2011*
CURRENTLY INSTALLED PV SYSTEMS	**528**	**2,135**	**100%**	**69%**	Excludes Uterne system
INSTALLED + PENDING UTERNE SYSTEM	**529**	**3,104**	**145%**	**100%**	Includes Uterne system

PV systems installed and pending installation on the Alice network as at April 2011

There have been a number of drivers for the rapid increase in PV systems connected to network in the last few years. These include: increasing community concern over climate change and a desire to support renewable energy; reducing PV system costs and reduced barriers to grid-connected PV systems; increasing electricity prices; and a range of broader government programs providing financial incentives and other support for the installation of PV systems, in particular the Australian Government funded Alice Solar City (ASC) project.

Alice Springs was selected in 2008 by the Australian Government to be one of seven "Solar Cities" under its national Solar Cities Program. The Alice Solar City project has helped facilitate many of the PV systems installed on the Alice network via specific ASC financial incentives as well as by providing a general broader support framework for the use of solar energy in Alice Springs. As a result the program has helped generate significant momentum in the community for the installation of PV systems, and the acceptance of this as "normal" practice.

As can be seen from the table above, in terms of numbers of PV systems connected, the vast majority are residential, with a much smaller number of commercial systems, and several large showcase/iconic systems. It can also be seen that a large portion of the PV systems installed has been under the auspices of the ASC project.

In terms of total PV capacity on the network, to date the majority has been attributable to residential PV systems, however with the pending connection of the Uterne 1MW PV system the majority of installed PV capacity will now be attributable to the several larger showcase/iconic systems, and near one third to the Uterne system in particular.

PV System Distribution Across the Network

The PV systems are reasonably well spread across the Alice network. A good distribution of PV systems across the network can help to reduce localised concentrations of PV capacity and therefore help reduce localised PV penetration effects. It can also help to reduce the effects on the system of passing clouds, particularly on the system-wide net power demand and hence the centralised generation system.

PV Penetration at the System-wide, Feeder and Distribution Transformer Levels

The two tables below summarise indicative system-wide PV penetration levels for PV capacity, PV peak power (summer and winter) and PV energy penetration for two separate cases. The first table is for the case of the existing amount of installed PV capacity as at the time of this report. The second table is for the case of the total installed PV capacity once the Uterne 1MW system is connected in July 2011.

PV Penetration Measure	PV Measure	Value	System Measure	Value	% PV Pen.
PV Capacity Penetration (%)	Installed Nominal PV Capacity	2.1 MW	Peak Load	55 MW	3.9%
PV Peak Power Penetration - Summer (%)	Est. Summer Midday PV Peak Power	1.7 MW	Ave. Summer Midday Load Demand	40 MW	4.3%
PV Peak Power Penetration - Winter (%)	Est. Winter Midday PV Peak Power	1.4 MW	Ave. Winter Midday Load Demand	26 MW	5.3%
PV Annual Energy Penetration (%)	Est. Annual PV Energy Generated	3.4 GWh	Annual Gross System Load	230 GWh	1.5%

Measures of existing levels of PV penetration at the system level (excluding Uterne 1MW)

PV Penetration Measure	PV Measure	Value	System Measure	Value	% PV Pen.
PV Capacity Penetration (%)	Installed Nominal PV Capacity	3.1 MW	Peak Load	55 MW	5.6%
PV Peak Power Penetration - Summer (%)	Est. Summer Midday PV Peak Power	2.6 MW	Ave. Summer Midday Load Demand	40 MW	6.5%
PV Peak Power Penetration - Winter (%)	Est. Winter Midday PV Peak Power	2.2 MW	Ave. Winter Midday Load Demand	26 MW	8.3%
PV Annual Energy Penetration (%)	Est. Annual PV Energy Generated	5.7 GWh	Annual Gross System Load	230 GWh	2.5%

Measures of expected levels of PV penetration at the system level (i.e. with Uterne 1MW system)

It can be seen that for existing levels of PV penetration (i.e. excluding the Uterne 1MW system), while PV energy supplied is relatively small at 1.5% of annual system load, PV power penetration is estimated to be around 5% of the load at midday on a sunny winter day. Interestingly system peak PV power penetration is estimated to be higher in winter than summer due to the considerably lower winter midday system load relative to the midday summer system load.

Upon connection of the Uterne 1MW system these PV power penetration levels will increase by around half raising the estimated peak PV power penetration measure at midday on sunny winter days to around 8%. The proportion of PV energy supplied will also increase to 2.5% of annual system load.

With respect to PV penetration levels at the feeder level, these are presently considered to be insignificant. However connection of the 1MW Uterne PV system will significantly increase PV penetration levels on the relevant feeder and P&W will be monitoring this closely.

With respect to PV penetration levels at the distribution transformer level, these are generally considered to be low and manageable at present, however there are some distribution transformers where PV penetration levels are at a level where P&W has decided to take steps to monitor and assess these circuits, particularly with respect to monitoring potential voltage impacts.

Key P&W Experiences to Date with Increasing PV Penetration Levels

In general, P&W is of the view that the present levels of PV penetration on the Alice Springs network are entirely manageable and have not caused any problems of significance to the safe and reliable operation of the Alice Springs electricity supply system.

P&W has had some specific experiences with increasing levels of PV penetration, and is also investigating more closely some other potential high PV penetration effects/issues which may arise in the foreseeable future. P&W has also considered other generally known potential PV penetration effects and determined them not to be an issue on the Alice network at present.

The table below provides a summary of these, listed in order of their significance, along with brief comments as to their current status.

As stated above, none of these items are considered by P&W to present any issues of significance to the safe and reliable operation of the network in the foreseeable future given the anticipated levels of PV system installation expected to occur.

P&W is of the view that there are areas where more information can be obtained and further analysis undertaken in order to better understand potential PV penetration issues and ensure they are appropriately managed.

PV Penetration Experience/Issue	Comment/Status
Significant tripping of PV systems during system frequency drop events.	Previously experienced during certain system low frequency events. Steps have been taken by P&W to address this by changing inverter low-frequency trip requirements (i.e. reduced to 46Hz). This issue has been resolved for connection of future PV systems but not yet fully resolved for existing PV systems on the network. There has been no significant impact on network operation. Raises a related issue concerning the ability or otherwise of utilities to confirm and change settings for existing inverters.
Small PV fluctuations on system net load profile due to clouds.	Recently observed (order of close to 1MW over period of minutes). No material impact on network operation as yet. To be monitored by P&W.
LV distribution system voltage management.	Presently no problems with LV system voltage due to PV penetration. However P&W has initiated a project to more closely investigate potential LV system voltage effects on a section of the network with high PV system penetration.
Reactive power management.	Presently no problems with reactive power management due to PV systems. However the general issue is currently being assessed/reviewed by P&W. Consideration is being given to larger systems (e.g. 100kW+) providing reactive power support.
Other potential PV penetration effects: • Reverse power flow • Network fault protection • PV system islanding • Harmonic injection	 ⇨ Not presently an issue. ⇨ Currently no issues due to PV systems. ⇨ Not experienced. ⇨ Not considered an issue (from PV systems).

Summary of Key P&W PV Penetration Experiences/Issues on the Alice Springs Network

Key Findings

This study has undertaken a relatively broad review of P&W's experiences with increasing levels of PV system penetration on the Alice Springs network.

Some of the key findings from the study are outlined below:

- The number and capacity of PV systems connected to the Alice Springs network has increased relatively rapidly over the last few years from only two small residential systems in 2008 to 528 systems of varying sizes as at April 2011 and with a total installed capacity of 2.1MWp. A further 1MWp system is due for connection in July 2011.
- The present levels of PV system penetration have not had a material impact on the safe and reliable operation of the Alice system and are presently considered entirely manageable by P&W.
- P&W has had one particular PV penetration experience of note which involved a significant loss of PV power on the network during several system frequency drop events in 2010. This issue has been largely resolved for new PV systems connected to the network, however it is not yet fully resolved for existing PV systems. This experience resulted in the following important findings:
    - P&W has subsequently set the low-frequency trip requirement for grid-connected PV inverters to 46Hz, which is below the lowest emergency load-shedding frequency level for the system. This has been done to keep PV systems on-line for as long as possible during frequency-drop events to ensure the situation is not worsened by a resulting rapid increase in system net load. This may be of relevance/interest to other utilities, particularly those with similar “small grids”.
    - P&W does not own or directly control the PV inverters connected to its network. It must direct the PV inverter owner or installer to change inverter settings if required by P&W, and this may not always occur in practice. This issue may increase in significance as more inverters are connected to the network and if future system-wide inverter setting changes are required.
    - Related to this, P&W does not presently have the ability to remotely interrogate inverters to confirm if inverter settings are correct, and remotely change them if not. P&W is of the view that this ability should be given further consideration by the relevant regulators and standards bodies, with a view to considering whether relevant codes should be changed to allow or require this (e.g. AS 4777).
- P&W has also identified three “potential” PV penetration effects/issues which are not currently causing problems on the network but may become more significant as PV penetration levels increase. P&W has already initiated further assessment of these, which are: potential effects of fluctuations in PV power output due to clouds (i.e. intermittency); potential effects on LV system voltage; and reactive power management.
- A number of other “possible” PV penetration effects/issues have been considered by P&W, however it does not consider these to be an issue now or in the foreseeable future. They are: reverse power flow, network fault protection, PV system islanding, and inverter harmonic injection.
- Connection of the Uterne PV system will add 1MW of PV capacity to the network, increasing overall system PV capacity by approximately 45%. P&W will be monitoring the operation of this system on the network closely.
- P&W expects the number and capacity of PV systems connected to the Alice network to continue to increase over time and hence PV penetration levels to increase, and that this will need to be managed carefully and pro-actively.
- As well as the PV penetration effects/issues already identified for further assessment by P&W above, this study has identified a number of possible areas for further investigation, and specific recommended actions within each. These areas are listed at the end of this Executive Summary. The specific recommendations have been provided to P&W and other Alice Springs PV stakeholders separately to this report.
- Some of these possible areas/actions for further investigation which are of particular note include:
    - Consider generally increasing the level of metering, monitoring and analysis of potential PV penetration effects.
    - Consider undertaking a more detailed assessment of the system-level PV power profile, to help assess system-level PV intermittency and its relationship to such things as PV system

size and distribution, cloud cover, the system net load profile, and the potential impact on the central generation system (e.g. power ramp-rate effects and spinning reserve requirements).

- Related to the above, consider investigating the best approach for connecting new PV capacity to the Alice network in terms of PV system size and distribution (e.g. centralised vs. distributed PV systems), given the impact such decisions will have on PV penetration levels and hence PV penetration effects, including on system-wide PV power intermittency.
- P&W to continue to monitor developments in the capabilities of PV system inverters, including: reactive power, fault ride-through and remote interrogation/control capabilities. Similarly, continue to identify and communicate any inverter requirements specific to "small grids" and other relevant applications in the Northern Territory.
- Decisions relating to the design and operation of the network need to factor in the likelihood of increasing levels of PV system penetration into the future, as such network decisions can have long term implications (for e.g. decisions on the procurement of network equipment and/or systems which will be used for many years to come).
- Consider co-ordinating some or all of this work with key Alice Springs PV stakeholders and/or broader research groups working in the area, as relevant.

Areas for Further Investigation and/or Action

P&W recognises that, due to a range of driving forces, it is highly likely the number and overall capacity of PV systems connected to the Alice network will continue to increase over time and that P&W needs to be prepared for this. This will involve ensuring that potential PV penetration issues are identified and managed in advance and that system planning and operational decisions factor in the potential for significant future PV system integration.

A number of areas for further investigation and/or action in relation to future management of PV penetration on the Alice Springs network have been identified during the case study. These include:

- Metering, Monitoring and Analysis;
- PV Power Fluctuations Due to Clouds (Intermittency)
- LV Distribution System Voltage Management
- Reactive Power Management
- Other Potential High PV Penetration Effects
- Inverter Capabilities and Requirements
- Network Planning and Operational Processes
- Knowledge and Skills Development
- Long-Term High PV Penetration Management Plan

Specific recommended actions within each area have been provided to P&W and other Alice Springs PV stakeholders separately to this report.

2 INTRODUCTION

This report presents a case study of one example of an Australian electricity grid with increasing levels of photovoltaic (PV) system penetration. The grid considered is the electricity supply system for the Alice Springs township in the Northern Territory, Australia.

This case study has been undertaken as part of a broader Australian research project titled "*Support for Australian participation in an international RD&D collaboration on Photovoltaics – IEA PVPS Task 14: High Penetration of Photovoltaic systems in electricity grids".* This research project is being co-ordinated by the Australian Photovoltaic Association (APVA[1]), in conjunction with the Centre for Energy and Environmental Markets (CEEM[2]) at the University of New South Wales, and with funding from the Australian Solar Institute (ASI[3]).

The broad aims of the overarching research project are to:

- enhance understanding of the technical, economic and regulatory requirements needed to achieve high levels of PV penetration in electricity grids in Australia; and
- support Australia's active participation in the International Energy Agency's Photovoltaic Power Systems Program Task 14 (IEA PVPS Task 14[4]) which provides a forum for all IEA countries to share knowledge and experiences on the integration of high levels of PV into electricity grids.

More detailed information on the IEA Task 14 program is provided in Appendix 1 along with links to further information resources on the integration of high levels of PV into electricity grids.

This case study is one of five being planned in Australia as part of the initial information gathering stage of the broader research project. A key aim in selecting the case studies has been to choose grid situations with relatively high levels of PV penetration by current Australian standards, as well as situations which are likely to provide learnings that are specific to an Australian context (e.g. small isolated grids). It is intended that these learnings can be fed back into the development of appropriate technical, regulatory, economic and policy mechanisms for facilitating high levels of PV penetration in electricity grids, both within Australia and in relevant situations internationally. Other sites with significant or rapidly increasing PV penetration currently being considered for case studies are:

- Magnetic Island (near Townsville, QLD)
- Norfolk Island (~1,500km east of Brisbane)
- Newington Olympic Village (Sydney)
- Carnarvon or Broome (WA)

Alice Springs has been selected for a case study for a number of reasons. Its electricity supply system is similar in many respects to small autonomous electricity networks supplying many isolated townships in Australia consisting of multiple large gas/diesel generators. As such it is representative of a particular type of electricity supply system often found in Australia. Alice Springs also has an excellent solar resource and strong stakeholder support for PV and solar energy generally. It was selected in 2008 by the Australian Government to be one of Australia's seven "Solar City" locations and as such has received funding support for the implementation of solar energy and energy efficiency programs through a body set up specifically to

[1] www.apva.org.au

[2] www.ceem.unsw.edu.au

[3] www.australiansolarinstitute.com.au

[4] www.iea-pvps.org/index.php?id=58

implement the program called the Alice Solar City[5] project. Subsequently over 500 PV systems have been installed on the Alice Springs electricity network over the last few years. Finally, there has been pro-active support from the key stakeholders in Alice Springs that need to be involved in such a case study for it to be of value. These are:

- The Northern Territory Power and Water Corporation[6] (P&W), which is responsible for the provision of water and electricity to customers in the Northern Territory, and owns and operates the Alice Springs electricity supply system;
- The Alice Solar City (ASC) project mentioned above; and
- The Centre for Appropriate Technology Projects Group (CAT Projects[7]), a key adviser, designer, installer and supporter of PV systems in Alice Springs.

In line with the aims of the broader APVA/CEEM High PV Penetration Research Project and the IEA PVPS Task 14 objectives, the primary aims of this case study are to identify and communicate P&W's key experiences to date with increasing levels of PV penetration on the Alice Springs electricity supply system from a technical perspective, and to identify areas that may require further investigation and/or study.

It is also noted that this report is intended to be a case study that can be made available to an international audience through the IEA PVPS Task 14 program and as such its intended audience is broad. However as mentioned above the primary focus is on the technical aspects of PV penetration in electricity grids and the report is therefore targeted towards an audience with a reasonable level of technical understanding in this subject area.

The remainder of this report consists of the following sections:

- Section 3 outlines the approach used in undertaking the case study;
- Section 4 describes the Alice Springs electricity supply system, PV systems on the network, and PV penetration levels.
- Section 5 discusses P&W's key experiences to date with increasing levels of PV penetration on the Alice supply system.
- Section 6 summarises the key findings of the Case Study.
- Appendix 1 gives an overview of the Task 14 IEA PVPS Program and provides links to information resources on high PV penetration in electricity grids.

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[5] www.alicesolarcity.com.au

[6] www.powerwater.com.au

[7] www.catprojects.com.au

3 CASE STUDY APPROACH

The broad approach taken by CEEM/APVA in undertaking the case study and preparing the report was as follows:

- Firstly confirmed the participation of the key Alice Springs Case Study stakeholders - P&W, ASC and CAT Projects. Liaised with the Northern Territory Government Energy Policy Climate Change Unit and Charles Darwin University Centre for Renewable Energy to appraise them of the project and its scope.
- Prepared key documents to be used during the case study and provided these to the key stakeholders, including:
  - A brief Case Study Project Overview outlining the project for stakeholders and others;
  - A System Level Questionnaire and Feeder Level Questionnaire intended for use during the Alice Springs site visit;
  - A tentative Alice Visit Schedule proposing activities to be undertaken during the visit.
  - An outline of the proposed structure of the Case Study Report.
- Finalised a detailed schedule of stakeholder meetings and PV system/network site visits for the Alice visit.
- Undertook a one-week visit to Alice Springs to meet staff from P&W, ASC and CAT Projects, as well as a local PV system installer (Agnew Solar). Collected information on PV penetration experiences and issues, visited electricity network systems and areas, and visited a selection of PV systems. At the end of the visit provided a more detailed outline of the proposed Case Study Report content to key stakeholders for review and feedback.
- Undertook post-visit clarification of information with P&W and prepared a draft Case Study Report for key stakeholder review and comment.
- Prepared the finalised Case Study Report following feedback on the draft report from key stakeholders.

The intention is for this Case Study Report to be sent to the key Alice Springs stakeholders and also made publicly available through the APVA to broader interested parties including the IEA Task 14 working group.

The Information presented in this report is based primarily on contributions from the people identified in Table 1 below which also outlines each person's role in the Case Study.

Name	Org.	Org. Position	Case Study Role
Dr. Muriel Watt	APVA	Chair	(Joint) Project Director
Assoc. Prof. Iain MacGill	CEEM	Join Director (Engineering)	(Joint) Project Director
Mark Hancock	CEEM	Researcher	Project Manager and Report Author
Steve Sawyer	P&W	Engineering Manager, Alice Springs	Provided extensive input, information and feedback on P&W experiences with increased PV penetration levels on the Alice network

Name	Org.	Org. Position	Case Study Role
Trevor Horman	P&W	Manager, Sustainable Energy	Provided considerable input and feedback on P&W perspectives on PV penetration issues on P&W network and related issues generally
Lyndon Frearson	CAT Projects	General Manager	Provided considerable input as a key Alice Springs PV stakeholder and PV system designer.
Brian Elmer	ASC	General Manager	Provided ASC support and ASC program perspectives.
Sam Latz	ASC	Commercial Services Manager	Provided considerable ASC information and feedback on the report, and arranged tours of several PV systems.
Chris Penna	ASC	Monitoring and Evaluation Manager	Provided information on ASC monitoring and evaluation programs.
Ben Frichot	Agnew Electric	PV System Installer	Provided a PV Installer perspective.

Table 1: People who contributed to the Case Study

It is noted that considerable effort has been made by CEEM to ensure that the information presented in this report is a fair and accurate reflection of communications with stakeholders, information provided and subject matters covered, including extensive discussions with P&W staff. Each of the key Alice Springs stakeholders – P&W, CAT Projects and ASC – have also been given the opportunity to provide input to the development of the report including review of the draft version of the report.

4 THE ALICE SPRINGS ELECTRICITY SUPPLY SYSTEM AND PV PENETRATION LEVELS

Alice Springs[8] is a township of approximately 30,000 people in the Northern Territory, Australia. Situated in the centre of Australia and approximately 450km from Uluru (or Ayers Rock) it is also a popular tourist destination.

The Australian Bureau of Meteorology (BoM) website[9] says the Alice Springs climate is “one of extremes” and that “not only does Alice Springs have hot summers and cold winters but the diurnal (intra-day) range in temperature can be up to 28°C”. Related to this it is also noted that air-conditioning is a significant electricity load on the Alice Springs network, particularly during summer months.

Further, having a primarily sunny and arid climate and being located on the Tropic of Capricorn, Alice Springs possesses an excellent solar energy resource. The BoM website identifies that Alice has an average of 9.6 sunshine hours per day and 200 clear days per year. This helps contribute to an average daily solar exposure of 22.3 MJ/m^2 which is high by Australian standards, as illustrated in the diagram below, and therefore very high by world standards.

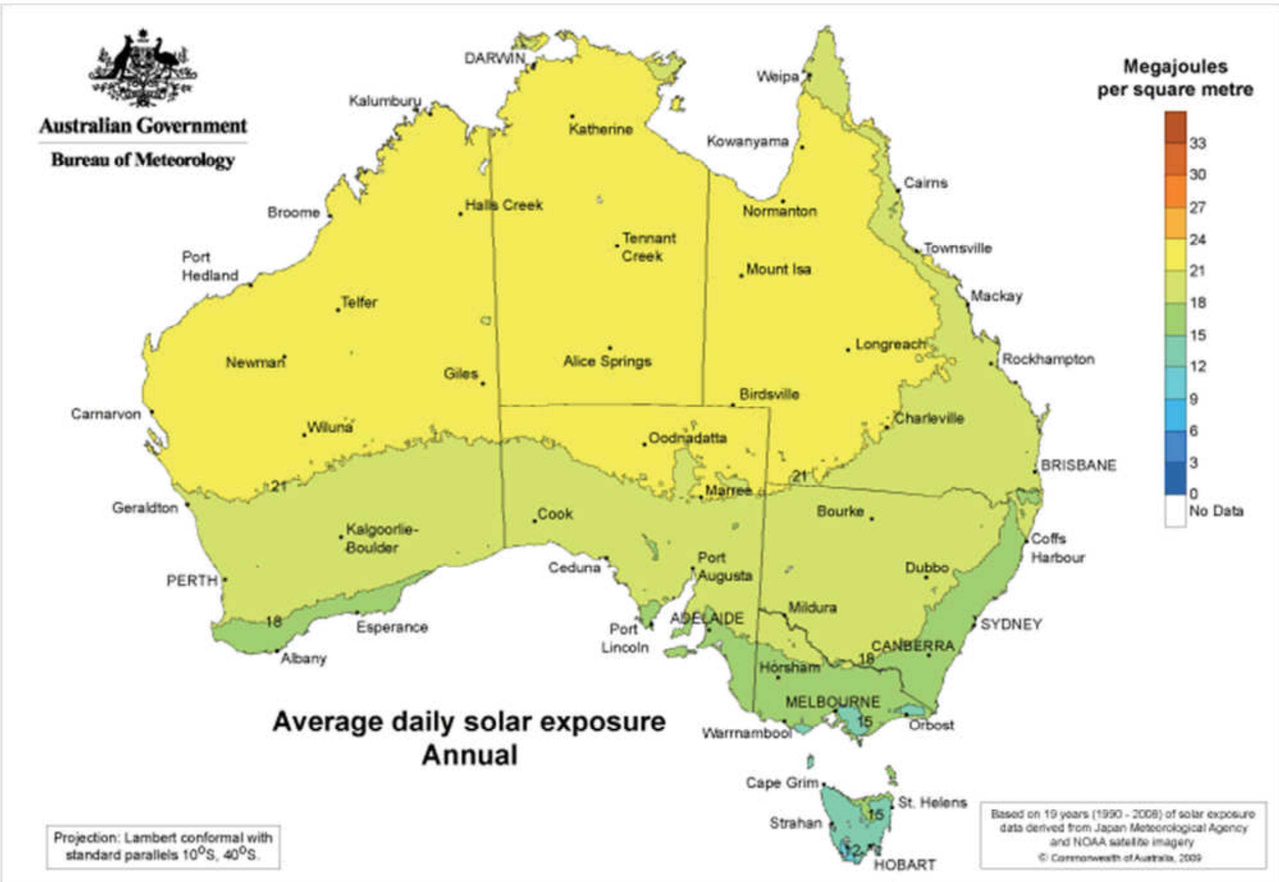

Figure 1: Average Daily Solar Exposure across Australia for the period 1990 to 2008 (Source: Australian Bureau of Meteorology website)

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[8] www.alicesprings.nt.gov.au

[9] www.bom.gov.au/nt/alicesprings/climate_and_history.shtml

4.1 The Alice Springs Electricity Supply System

The Northern Territory Power and Water Corporation (P&W) is responsible for the provision of electricity and water to customers throughout the Northern Territory including the Alice Springs township.

P&W owns and operates the Alice Springs electricity supply system which is an isolated network primarily supplying the Alice Springs township. Some outlying rural areas of up to 80km away are also supplied however these represent a small proportion of the load (only 5% of customers are classified as rural). The electricity load on the network is residential (~70% of customers) and commercial. No customers are classified by P&W as industrial.

The system has three main centralised power stations incorporating nineteen dual-fuel gas/diesel generators with a combined generation capacity of approximately 100 MW. These are connected to a high voltage sub-transmission and distribution network which feeds power to and throughout the Alice township and outlying areas. The only distributed generation systems on the network are photovoltaic (PV) power systems. These have increased in number and capacity significantly over the last three years to the point where, as at the time of writing of this report, there were 528 PV systems distributed across the network with a combined nominal peak capacity of 2.1MWp. An additional 1MWp PV system (known as Uterne) is also due to be connected in July 2011. The network peak load occurs on summer afternoons and is presently around 55MW, while the minimum load typically occurs late at night outside of summer and is presently around 15MW. The average load in 2010 was 26MW.

The table below summarises these key system parameters. A more detailed description is given further below of the centralised generation system, the transmission/distribution system, and the system load.

Peak Power Demand (indicative)	55 MW
Minimum Power Demand (indicative)	15 MW
Average Power Demand (indicative)	26 MW
Annual Energy Consumption (indicative)	230 GWh
Central Generation Capacity	100 MW
Existing PV Capacity (as at April 2011)	2.1 MWp
Existing PV Capacity + Uterne 1MW system	3.1 MWp

Table 2: Summary of Key Alice Springs Supply System Parameters

Of the three centralised power stations, the primary one to date has been the Ron Goodin power station located on the eastern edge of the township. It has twelve dual-fuel natural gas/diesel generators with natural gas being the primary fuel. These generators range in capacity from 2MW to 12MW. Ron Goodin power station currently supplies the majority of Alice's load requirements however P&W plans to progressively replace generation from this station with generation from the new Owen Springs power station currently being built and commissioned approximately 25km south of Alice. The Owen Springs station has three 10.9MW dual-fuel natural gas/diesel generators with the primary fuel again being natural gas. Electricity from Owen Springs will be transmitted to Alice Springs via two 66kV lines. The third power station (Brewer) is located close to the Owen Springs power station however it is privately owned and operated whereas the other two are owned and operated by P&W. Brewer contains four natural-gas fired 2.1MW generators and operates as a relatively constant power output base-load power station, with output typically in the range 6-8MW due to its contract with P&W. Natural gas is supplied to Alice Springs and the power stations from nearby natural gas fields and also via a pipeline from Darwin, whereas diesel fuel is trucked in.

The network's sub-transmission system consists of two 66kV lines between Owen Springs power station and the main Lovegrove zone substation located in the Alice township. The high voltage distribution system consists of both 22kV and 11kV feeders, with the 22kV feeders primarily distributing power between the power stations and the zone/switching stations or to the outlying rural areas, while the 11kV feeders primarily distribute power throughout the township.

The system load profile varies significantly by season. **Figure 2** and **Figure 3** below contain indicative examples of summer and winter daily load profiles respectively (for a sunny week-day). These load profiles represent the combined load supplied by the central power stations.

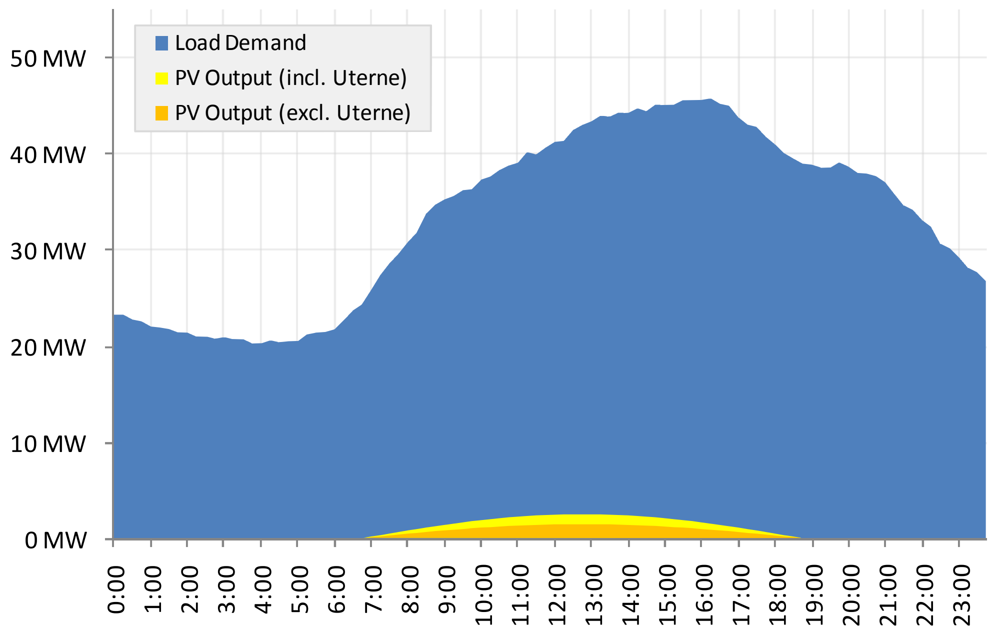


Figure 2: Example Summer Daily Load and PV Output Profiles (for a sunny week-day) for the Alice System

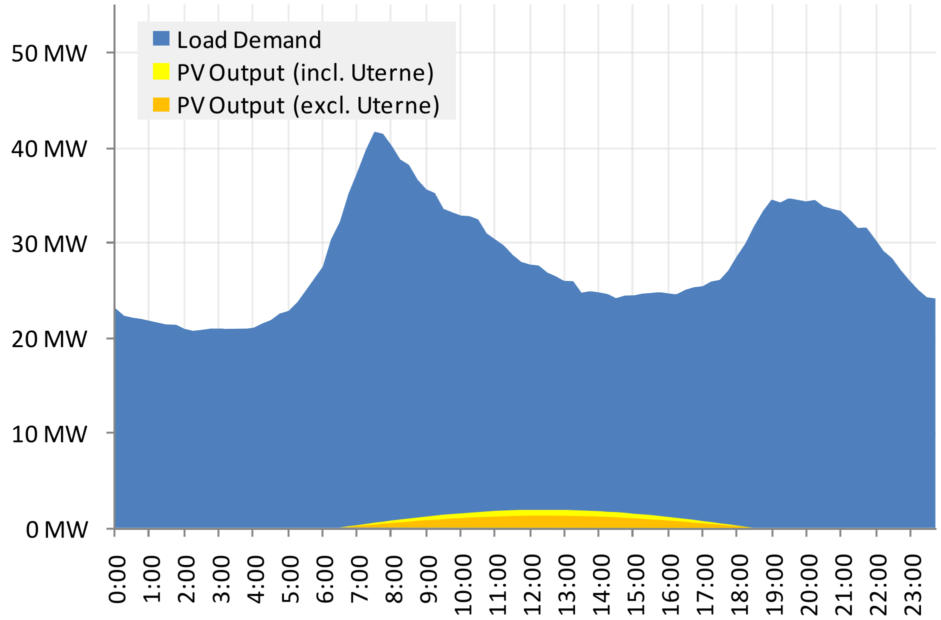


Figure 3: Example Winter Daily Load and PV Output Profiles (for a sunny week-day) for the Alice System

Note that for illustrative and comparison purposes two PV output profiles have been included in the figures: the smaller (orange) PV profile represents an estimate of the existing overall PV output power on a sunny day from PV systems currently on the network; the slightly larger (yellow) profile represents an estimate of the overall PV output on a clear day once the Uterne 1MW PV system is connected. Details of PV systems on the network are provided in the next section.

The summer load profile is heavily influenced by cooling loads and in particular air-conditioning, rising consistently during the morning and the middle of the day before peaking around mid-to-late afternoon and then falling away again during the evening.

The winter load profile is dominated more by morning and evening residential activity periods, including associated heating requirements. The load picks up fairly rapidly in the morning then gradually tapers off during the day before peaking again in the evening and then falling away again at night.

It is noted that the average midday winter load on a sunny day (i.e. when the daily PV power would be peaking) is around 26MW, a little lower than the midday value in the winter profile shown above. This is considerably lower than the average midday summer sunny day load of around 40MW. These values are relevant to the discussion later in this report on system-wide PV penetration levels in Section 4.4.1.

It is further noted that from a perspective of rate of change of load and its impact on the centralised generation system (e.g. for spinning reserve requirements) the most significant sustained load ramp rates occur during winter mornings (highest ramp rate), winter evenings, and summer mornings.

It is also noted that Alice Springs has a relatively high average residential electricity demand of around 23kWh[10] per day. There are a number of factors causing this but a key one is air-conditioning demand.

[10] See www.alicesolarcity.com.au/solar-pv-systems which states 8,500kWh per year (~23 kWh/day)

4.2 PV Systems on the Network

Prior to 2008 there were two small residential PV systems connected to the Alice network. There are now 528 systems connected with a combined capacity of 2.1MWp, with another 1MWp system to be connected in July this year which will bring the total installed peak capacity to 3.1MWp. **Table 3** further below provides a summary of the PV systems on the Alice network.

There have been a number of drivers for the rapid increase in the number of PV systems connected to system in the last few years. These have included: increasing community concern over climate change and a desire to support renewable energy; reducing PV system costs and reduced barriers to grid-connected PV systems; increasing electricity prices; and, in particular, a range of government programs providing financial incentives and other support for the installation of PV systems. Particular Australian government programs that have provided financial support for the installation of PV system's in Australia over recent years have included: the Photovoltaic Rebate Program (PVRP); the Solar Homes and Communities Program (SHCP); the 20% Renewable Energy Target (RET), the Remote Renewable Power Generation Program (RRPGP), and the Solar Cities Program.

Alice Springs was selected in 2008 by the Australian Government to be one of seven "Solar Cities" under its national Solar Cities Program. The Alice Solar City (ASC) project has helped facilitate many of the PV systems installed on the Alice network via specific ASC financial incentives as well as by providing a general broader support framework for the use of solar energy in Alice Springs. As a result the program has helped to generate significant momentum in the community for the installation of PV systems, and the acceptance of this as "normal" practice. The project also aims to capture data and learnings from its solar programs which it is intended will be fed back into the development of future government solar programs, energy policy, regulation and other solar support mechanisms generally.

Category	#	Capacity (kWp)	% Inst. Cap	% Inst. + Pend. Cap	Comments
Residential Systems					
Installed under ASC program	277	530	25%	17%	Mostly 2kW (some 1 & 1.5kW)
Installed outside ASC program	183	464	22%	15%	1.5kW to 5kW systems
Total Residential	**460**	**994**	**47%**	**32%**	
Commercial Systems					3kW to 40kW systems
Installed under ASC program	35	367	17%	11.8%	
Installed outside ASC program	4	14	1%	0.5%	
Total Commercial	**39**	**381**	**18%**	**12%**	
Iconic/Showcase Systems					
Desert Knowledge Solar Centre	27	220	10%	7%	Showcase (2008)
Crowne Plaza Hotel	1	305	14%	10%	ASC Iconic (early 2009)
Alice Springs Airport	1	235	11%	8%	ASC Iconic (Nov 2010)
Total Installed Iconic/Showcase	**29**	**760**	**36%**	**24%**	
Uterne Solar System (pending)	*1*	*969*	*45%*	*31%*	*ASC Iconic - due July 2011*
CURRENTLY INSTALLED PV SYSTEMS	**528**	**2,135**	**100%**	**69%**	Excludes Uterne system
INSTALLED + PENDING UTERNE SYSTEM	**529**	**3,104**	**145%**	**100%**	Includes Uterne system

Table 3: PV systems installed and pending installation on the Alice network[11], as at April 2011

The Alice Solar City project is overseen by a consortium of local public and private organisations that have supported the development of the project over a number of years. The consortium members are:

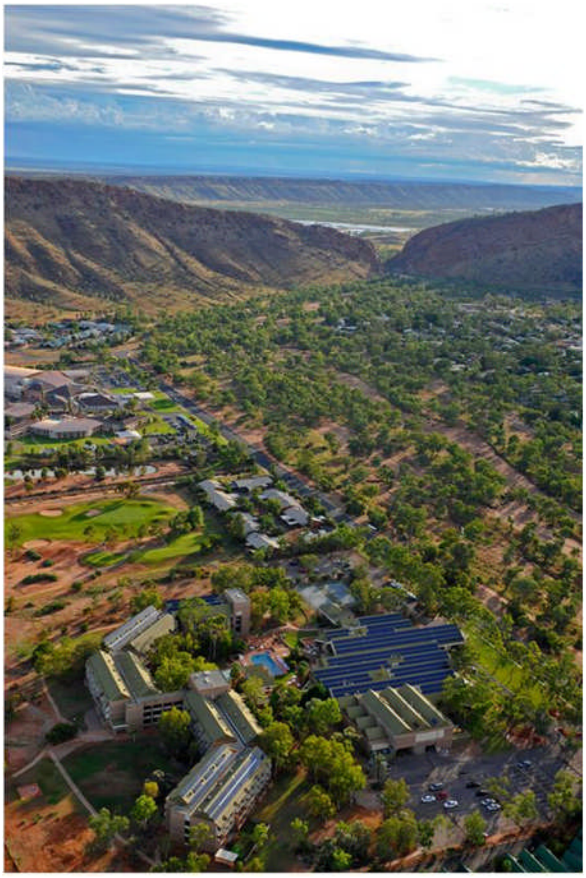
- Alice Springs Town Council;
- Northern Territory Government;
- Power and Water Corporation;
- Arid Lands Environment Centre;
- Tangentyere Council; and
- Northern Territory Chamber of Commerce and Industry.

It is also noted that the Northern Territory, and P&W in particular, have a long history of involvement in the utilisation of PV systems, particularly for the supply of power to remote communities.

It is noted that the pending Uterne PV system has been specifically separated in the capacity totals in the above table as it was yet to be connected at the time of preparing this report (due for commissioning in July), and also because it will significantly increase the PV capacity currently on the network (by approximately 45%). As such it is noted that the review of key experiences to date with PV system penetration on the Alice Network, as discussed in Section 5, does not include any impacts of the Uterne

[11] PV system summary data provided by P&W.

system as it was not yet connected at the time of preparing this study. Specific references however are made to this system throughout the report where relevant, as it will represent a significant increase in PV penetration and P&W intend to monitor its integration closely.



Aerial shot of the Crowne Plaza Hotel 305kWp rooftop PV system, and a view towards the south of Alice Springs. (photo courtesy CAT Projects)

While the vast number of the systems currently installed are residential (~90%), at around 2kW each they only represent a little under half (47%) of the total PV capacity on the network and this will reduce to around one third of capacity (32%) once the Uterne system is connected. Of these 460 residential systems the majority (277) were installed under the ASC program. However ASC funding support for residential PV installations has now mostly finished and so all recent residential PV installations have been undertaken outside of the ASC program. An important point to note regarding the 277 ASC systems is that smart-meters were installed in these customer's premises allowing metering and logging both of household 'gross' (as opposed to 'net') load consumption and PV system power output. Further, households with PV systems installed under the Solar City incentive program also received an in-house energy display unit which displays among other things household load and PV power profiles as well as electricity tariff charges and revenue (i.e. for any exported PV power) based on actual metered data. The 183 residential PV systems installed outside the ASC program typically receive utility meters that are configured as simple consumption meters that measure total PV system output and total load consumption separately but are not configured to measure interval data or support in-house energy displays. For a small percentage of customers (either ASC or non-ASC) where it is considered impractical to apply gross meters, simpler net metering is used however a check meter is usually also installed which measures gross PV system output. These households also do not have in-house energy display units unless they are separately purchased and set up by the household. These different approaches to metering and monitoring obviously result in different levels of energy data being available for these PV systems and their associated households, for monitoring and analysis purposes.

The 39 PV systems classified as 'commercial' (i.e. owned by businesses but not large enough to be classified as 'iconic' systems) range in size from 3kW to 40kW nominal capacity and represent 17% of installed PV capacity (12% after connection of Uterne). Most of these have been installed under the ASC program and therefore have smart-meters installed allowing interval metering and logging of both site load consumption and PV system output power separately. Commercial PV systems installed under the ASC program will generally also have the in-house energy display units referred to previously. For purchasers of commercial PV systems both inside and outside the ASC incentive program it is also noted that at least one PV installer is encouraging these businesses to also purchase a product/service (provided by one of the main PV inverter manufacturers) whereby a data logging device with remote communication capability is connected to the PV system's inverter and this device sends PV system operational data to a central data warehouse (maintained by the PV inverter manufacturer) where it is stored and made available on a website accessible by the customer and anyone else with authorised access (e.g. the PV installer). PV system data (e.g. general system statistics, daily power output profiles etc) can also be made publicly available via the website if the customer so chooses. This service can also be used by the PV installer to receive inverter-identified system alarms and interrogate the inverter in the case of PV system failures/errors.

The "Showcase" system is the Desert Knowledge Australia Solar Centre[12] which is a grouping together of 27 smaller PV systems of varying PV technology types in a single "solar precinct". This PV demonstration site was developed in 2008 (prior to ASC) by a local NGO, The Centre for Appropriate Technology, for the purpose of showcasing PV technologies and enhancing community understanding of PV systems, among other objectives.

The three "Iconic" systems (i.e. Crowne Plaza, Alice Airport and Uterne) are large individual PV projects that have been partly financially supported by the Australian Government via the ASC program with the stated aim of "making Alice Springs a national and international showcase for sustainable living and the use of renewable energy"[13].

Once Uterne is connected, these four "Iconic/Showcase" systems will represent over half the PV capacity on the network. The Uterne system (referred to from here-on in this report as the Uterne 1MW system[14]) will itself represent close to one third of the installed PV capacity on the network.

Part of the Desert Knowledge Solar Centre PV Showcase Facility.

With regards to anticipated levels of PV system installation in the future, with the exception of the Uterne 1MW system incorporated into the figures in the above table it is difficult to estimate this and no specific projections are currently available. It is noted that the Australian Government's Solar City program is scheduled to finish in mid 2013 and so further subsidisation of PV systems through the Solar City program are likely to be limited. Either way, it is understood that discussions have already commenced among ASC program stakeholders on options to support solar initiatives in Alice Springs after this date. It is quite likely that future drivers of PV installations will come more from reductions in PV system costs, other government incentives such as the Federal Government's Renewable Energy Target and the Northern Territory Government's climate change and renewable energy targets, and likely ongoing rises in the costs of diesel fuel, natural gas and electricity prices generally. These factors may make the installation of PV systems an increasingly attractive option for households, businesses and even utilities themselves from a purely cost perspective (e.g. displacing more expensive generation options such as the use of diesel fuel, or even natural gas in certain situations).

[12] www.dkasolarcentre.com.au

[13] www.alicesolarcity.com.au/iconic-projects

[14] Although nominally 969kW it is referred to in this report as the Uterne 1MW system for simplicity and to indicate its size and significance relative to all the other PV systems on the network.

4.3 PV System Distribution

This section briefly discusses the general level of distribution of PV systems across the network, while the next section describes PV penetration levels in terms of capacity, power and energy penetration at different levels of the system (e.g. system-wide level, feeder level, distribution transformer level).

The level of PV system distribution across a network is important and is closely interlinked with PV penetration levels on the network. For example, if PV system capacity is not evenly spread across the network then there can be high localised levels of PV power penetration which could potentially cause localised network problems (e.g. voltage problems). Similarly if PV system capacity is relatively evenly distributed across the network, this can help minimise negative PV penetration effects. As a particular example, an even distribution of PV system capacity across the network can help minimise the transient effects of passing clouds on overall system PV output power, and therefore on the centralised generation system (i.e. minimising any resulting rapid power output response requirements on the centralised generators and also minimising generator spinning reserve requirements). However if PV capacity is highly concentrated in particular PV systems or specific localised areas of the network then the effects of passing clouds on overall system PV output power could be significant, causing large and rapid swings in system PV output power and therefore requiring equally large and rapid changes in the output of the centralised generators. This may also require spinning reserve levels to be raised and may have other negative effects (e.g. increasing operating costs and reducing generator life).

Figure 4 further below contains a diagram provided by P&W illustrating the distribution of PV systems across the Alice network by the number of PV systems per distribution transformer, as at 1st October 2010.

It is noted that while this diagram does not cover all the PV systems included in the summary in **Table 3** (for example systems connected after the 1st October are not included such as the Alice Springs Airport ‘Iconic’ system, and a number of commercial and residential systems) it is understood to cover at least 75% of these systems and therefore provides a relatively good representation of the spread of PV systems by number across the Alice network. It is also noted that the diagram does not provide an indication of the total PV capacity on each distribution transformer, however P&W has said it will consider this in the development of future PV distribution maps.

Alice Springs Airport 235kWp PV System (photo courtesy Alice Solar City Project).

The diagram in **Figure 4** indicates that the PV systems are reasonably well spread across the network and relatively well spread across distribution transformers, with only one distribution transformer having from 11 to 18 PV systems connected (all are residential systems), only three transformers having from 8 and 10 PV systems connected, and the remaining distribution transformers having less than 8 PV systems connected. It is also observed that the highest concentration of PV systems is in the north-east section of the network where the red dot appears on the map, which is a residential area. This section of the network is now the subject of a PV-related network voltage study which is discussed further in Section 5.4. It is noted that the distribution transformers supplying urban residential customers on the Alice network typically supply around 80 to 100 customers so these numbers of PV systems per distribution transformer (which are mostly in urban residential areas) still represent no more than 20% PV penetration by customer number at the distribution transformer level, and typically well less than 10% PV penetration by customer numbers per distribution transformer. It is also noted that the three existing large 'Iconic'/'Showcase' systems are connected to the network at quite physically distant locations, with the Crowne Plaza system located just south-east of the town centre, the Desert Knowledge Solar Centre located approximately 9km south of the town centre, and the Airport system located (not surprisingly) at the Airport which is about 14km south of the township. It is understood the Uterne 1MW system is to be located on P&W land located near to the Desert Knowledge Solar Centre.

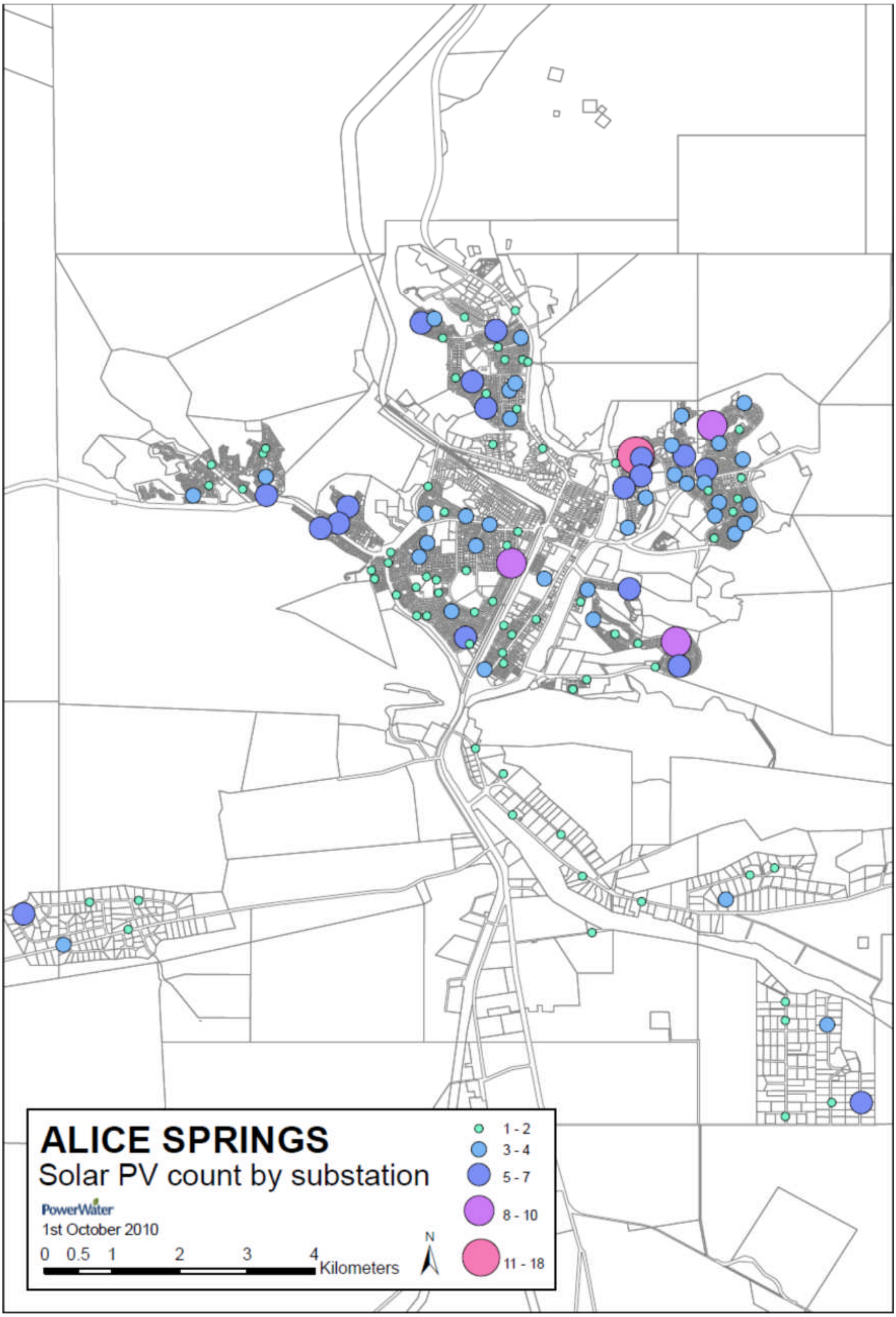


Figure 4: Diagram of PV System Distribution on the Alice Springs Network (Oct 2010)

4.4 PV Penetration Levels

This section discusses levels of PV penetration on the Alice supply system in terms of PV capacity, power and energy penetration at the following levels:

- system-wide level;
- feeder level;
- distribution transformer level.

4.4.1 PV Penetration at the System-Wide Level

The two tables below summarise indicative system-wide PV penetration levels for PV capacity, PV peak power (summer and winter) and PV energy penetration for two separate cases. The first table is for the case of the existing amount of installed PV capacity as at the time of this report, and the second table is for the case of the total installed PV capacity once the Uterne 1MW system is connected in July 2011.

PV Penetration Measure	PV Measure	Value	System Measure	Value	% PV Pen.
PV Capacity Penetration (%)	Installed Nominal PV Capacity	2.1 MW	Peak Load	55 MW	3.9%
PV Peak Power Penetration - Summer (%)	Est. Summer Midday PV Peak Power	1.7 MW	Ave. Summer Midday Load Demand	40 MW	4.3%
PV Peak Power Penetration - Winter (%)	Est. Winter Midday PV Peak Power	1.4 MW	Ave. Winter Midday Load Demand	26 MW	5.3%
PV Annual Energy Penetration (%)	Est. Annual PV Energy Generated	3.4 GWh	Annual Gross System Load	230 GWh	1.5%

Table 4: Measures of existing levels of PV penetration at the system level (excluding Uterne 1MW)

PV Penetration Measure	PV Measure	Value	System Measure	Value	% PV Pen.
PV Capacity Penetration (%)	Installed Nominal PV Capacity	3.1 MW	Peak Load	55 MW	5.6%
PV Peak Power Penetration - Summer (%)	Est. Summer Midday PV Peak Power	2.6 MW	Ave. Summer Midday Load Demand	40 MW	6.5%
PV Peak Power Penetration - Winter (%)	Est. Winter Midday PV Peak Power	2.2 MW	Ave. Winter Midday Load Demand	26 MW	8.3%
PV Annual Energy Penetration (%)	Est. Annual PV Energy Generated	5.7 GWh	Annual Gross System Load	230 GWh	2.5%

Table 5: Measures of expected levels of PV penetration at the system level (i.e. after connection of the Uterne 1MW system)

It is noted that the values for PV peak power and PV energy in the above tables are estimates only, based on total installed PV capacity and an estimated likely average output factor for PV systems across the network at the times nominated, as there is currently no collated information available on PV power and energy supplied by all PV systems across the network to provide actual values for these measures.

It can be seen that for existing levels of PV penetration (excluding Uterne), while PV energy supplied is relatively small at 1.5% of annual system load, PV power penetration is around 5% of the load at midday on a sunny winter's day. Interestingly PV power penetration is estimated to be higher in winter due to the considerably lower winter midday system load relative to the midday summer system load.

Upon connection of the Uterne 1MW system, these power penetration levels will increase by around 50%, raising the estimated peak PV power penetration measure at midday on sunny winter days to around 8%. The proportion of PV energy supplied will also increase to 2.5% of annual load.

While percentage penetration levels are important to understand the amount of PV power relative to the system power as whole, a key PV penetration figure at the system level is the actual magnitude of the total system PV power at any one time. This is because of its potential effect on the system's centralised generation system if this amount of PV power (or some significant portion of it) were to suddenly either drop out or cut in (e.g. due to clouds or other effects). This could have implications on the Alice Springs network for the control and operation of the gas/diesel generators, including spinning reserve requirements and the effects of system "events" (e.g. system faults), particularly if installed PV capacity were to continue to increase. The maximum PV power on the network at any one time based on existing installed PV system capacity is estimated to be around 1.6MW (i.e. around midday on a sunny summer's day). This is estimated to increase to around 2.5MW with the connection of the Uterne system.

P&W PV penetration experiences to date at the system-level relating to PV systems dropping out and PV power fluctuations being observed on the system net load profile are discussed in Sections 5.2 and 5.3 later. However, it is noted here that these experiences have either largely since been resolved (first case) or are not currently of concern (second case), and that P&W is of the view that the current levels of PV penetration at the system level are entirely manageable. P&W will however be closely monitoring the additional impact of the Uterne 1MW PV system once connected.

4.4.2 PV Penetration at the Feeder Level

There are two 66kV feeders and approximately twenty 22kV or 11kV feeders on the Alice network. With the exception of a few feeders to sparser outlying rural areas, most of the 22kV/11kV feeders are rated at around 5MW to 10MW capacity. Given the relatively broad distribution of existing PV systems across the network there is generally a very low level of PV penetration at the feeder level in terms of capacity.

For example the highest level of PV capacity penetration on a single feeder will be the pending connection of the Uterne 1MW system to a 22kV feeder of 10MW capacity. As identified in the table below, the PV capacity penetration on this feeder would be 10%. The feeder commonly supplies power in both directions with power flows typically of the order of 3MW. As such the PV power penetration on this feeder could be high relative to the load (33% indicative peak PV load penetration) but is still well within the power rating limits of the feeder. Nevertheless P&W intends to closely monitor the operation of the Uterne PV system on this feeder to assess a variety of operational characteristics.

Feeder rating	10 MW
PV system capacity on feeder	1 MW
PV capacity penetration	10%
Indicative load on feeder	3 MW
Indicative PV peak power/load penetration	33%

Table 6: Indicative figures for Alice network feeder with highest PV penetration (Uterne 1MW PV system)

All other 22/11kV feeders have total PV system capacities on them of no more than several hundred kW which P&W considers of low significance from a power penetration perspective given the typical operating loads on these feeders are normally of the order of MW.

In summary P&W does not consider PV penetration at the feeder level of significance at this point in time.

4.4.3 PV Penetration at the Distribution Transformer Level

As stated earlier, in late 2010 P&W in conjunction with Charles Darwin University's (CDU) Centre for Renewable Energy undertook an assessment of the distribution of PV systems on the network at the distribution transformer level (refer previously discussed **Figure 4** in Section 4.3). This was conducted as part of a project to assess the potential impact of high penetrations of PV systems on distribution voltage levels.

P&W and CDU chose to focus their study on a street section supplied by the distribution transformer on the Alice network with the highest number of connected PV systems (the red dot in **Figure 4**).

Based on discussions with P&W, this distribution transformer represents the highest PV penetration in terms of numbers of PV systems connected to a distribution transformer so it is considered briefly here.

As shown in the table below this distribution transformer has a nominal capacity of 300kW and supplies around 110 residential customers. It had 17 PV systems of 2kW capacity connected as at 1st October 2010, giving a total PV capacity of 34kW and an 11% PV capacity penetration on the distribution transformer. The average demand per customer on the transformer around midday (i.e. time of peak PV power) is estimated to typically be around 1kW giving an expected midday load demand on the transformer of around 110kW and an indicative maximum PV power penetration of about 31%.

Distribution transformer rating	300 kW
PV capacity on transformer	34 kW
PV capacity penetration	11%
# Customers supplied	110
Est. average midday demand per customer	1 kW
Est. average midday load on transformer	110 kW
Indicative maximum PV power/load ratio	~31%

Table 7: Indicative figures for distribution transformer with highest PV penetration

So from a PV power penetration perspective this is well within the design limits of the transformer and still not significant compared to the existing load. However P&W is aware that increasing levels of PV penetration may lead to voltage management issues and as such has undertaken the voltage study with CDU. P&W is also planning to apply meters to selected distribution transformers with high levels of PV system penetration to monitor voltage, current and power levels and undertake an assessment based on actual measure data.

5 KEY EXPERIENCES TO DATE WITH INCREASING PV PENETRATION LEVELS

5.1 Overview

The information presented in this section is based primarily on discussions with, and data provided by, P&W staff mentioned in Section 3. It is intended to represent the key experiences, from a technical perspective, that P&W has had to date with increasing levels of PV penetration on the Alice Springs network. Discussions with other Alice Springs PV stakeholders, also mentioned in Section 3, have been considered in preparing the information in this section.

In summary, P&W is of the view that the present levels of PV penetration on the Alice Springs network are entirely manageable and have not caused any problems of significance to the safe and reliable operation of the Alice Springs electricity supply system.

P&W has had some specific experiences with increasing levels of PV penetration, and are also investigating more closely some other potential high PV penetration effects/issues which may arise in the foreseeable future. They have also considered other generally known potential PV penetration effects and determined them not to be an issue at present.

The table below provides a summary of these, listed in order of their significance, along with brief comments as to their current status.

PV Penetration Experience/Issue	Comment/Status
Significant tripping of PV systems during system frequency drop events. (Section 5.2)	Previously experienced during certain system low frequency events. Steps have been taken by P&W to address this problem by changing inverter low-frequency trip requirements (i.e. reduced to 46Hz). This issue has been resolved for connection of future PV systems but not has not yet been fully resolved for existing PV systems on the network. There has been no significant impact on network operation. Raises a related issue concerning the ability or otherwise of utilities to confirm and change settings for existing inverters.
Small PV fluctuations on system net load profile due to clouds. (Section 5.3)	Recently observed (order of close to 1MW over period of minutes). No material impact on network operation as yet. To be monitored by P&W.
LV distribution system voltage management. (Section 5.4)	Presently no problems with LV system voltage due to PV penetration. However P&W has initiated a project to more closely investigate potential LV system voltage effects on a section of the network with high PV system penetration.
Reactive power management. (Section	Presently no problems with reactive power management due to

PV Penetration Experience/Issue	Comment/Status
5.5)	PV systems. However the general issue is currently being assessed/reviewed by P&W. Consideration is being given to larger systems (e.g. 100kW+) providing reactive power support.
Other potential PV penetration effects (Section 5.6): • Reverse power flow • Network fault protection • PV system islanding • Harmonic injection	 ⇨ Not presently an issue. ⇨ Currently no issues due to PV systems. ⇨ Not experienced. ⇨ Not considered an issue (from PV systems).

Table 8: Summary of Key P&W PV Penetration Experiences/Issues on the Alice Springs Network

None of these items are considered by P&W to present any issues of significance to the safe and reliable operation of the network in the foreseeable future given the anticipated levels of PV system installation expected to occur.

P&W is of the view that there are areas where more information can be obtained and further investigation undertaken in order to better understand potential PV penetration issues and ensure they are appropriately managed. Some of these are identified in the following sections.

In addition, as a result of this case study a number of areas for further investigation have been identified, along with specific recommendations within each area. These have been provided to P&W and other Alice Springs PV stakeholders separate to this report. The general areas for further investigation are outlined at the end of Section 6.

5.2 Tripping of PV Systems During System Frequency Drop Events

5.2.1 System Frequency Drop Events Causing Loss of PV Power

In large, well-interconnected "high-inertia" electricity networks such as those in the US and Europe the system frequency cannot deviate outside very tight limits at the risk of system-wide instability. For example in the European electricity supply network the normal operating frequency range is 50Hz +/- 0.02Hz[15].

However in smaller "low inertia" electricity supply systems such as the one in Alice Springs, system frequency can vary over a considerably larger range. The normal operating frequency range on the Alice Springs network is 50Hz +/- 0.1 Hz. However in certain situations (typically during "generation events" such as a generator failure) the frequency can vary quite significantly outside this range (e.g. up to several Hz) and very quickly.

If the frequency does fall significantly below the normal operating level, a priority load-shedding schedule must be implemented based on specified frequency levels to the point where the most critical loads are the last to be shed at around 47Hz. It is therefore desirable in these low frequency situations for as much

[15] www.entsoe.eu/system-operations/the-frequency/

generation as possible to be available to the system to meet the load demand and bring the system frequency back within normal limits.

During 2010 there were several system frequency drop events on the Alice network where the frequency fell below 49.9Hz. These events were caused by problems with the operation of the gas-fired generators. For the events that occurred during sunny days the system operators observed that when the frequency fell below 49.9Hz, the load, instead of also reducing as expected when frequency drops, suddenly increased in the order of 1MW before progressively reducing again to the original load level over a period of several minutes, once the situation with operation of the gas-fired generators had been resolved and the system frequency had returned above 49.9Hz.

After investigating the events P&W came to the conclusion that this sudden 1MW rise in load 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. PV system inverters connected to the Alice Springs network prior to that time had been programmed with frequency trip settings of 50Hz +/- 0.1Hz which it is understood were the default settings programmed into the inverters during manufacture in line with European grid-connection requirements.

Grid-connected inverters in a commercial rooftop PV system in Alice Springs (photo courtesy Alice Solar City Project).

There was close to 2MW installed nominal PV capacity on the network at the time of the frequency events concerned which occurred during the middle of the day in winter, and so the PV power output across the system would have been of the order of 1MW which correlated reasonably well with the size of the sudden increase in load.

P&W tested this theory by briefly reducing the system frequency below 49.9Hz in a similar manner late at night (i.e. when no PV power was on the system) with the result being effectively no change in load, which gave further support to the view that the sudden rise in load had been due to the PV systems dropping out.

5.2.2 Changes to P&W Requirements for PV Inverter Low-Frequency Trip Settings

A review of these events by P&W brought it to the conclusion that it would be desirable for the low-frequency trip settings for all PV inverters on the network to be altered to 46Hz. The reasoning being P&W wants the PV systems to stay on-line for as long as possible during system low frequency events (i.e. at least until the last load is shed at 47Hz at which time the whole network load is effectively shed) in order to keep the load on the central gas-fired generators as low as possible to help them ride through such events.

P&W has also set its high-frequency trip setting requirement for inverters at 54Hz such that the overall inverter frequency trip settings are 50Hz +/- 4Hz.

P&W considers this issue an example of how the integration of PV systems into electricity grids needs to be flexible with respect to the particular characteristics and requirements of the electricity system in question, and that such flexibility needs to be allowed for in standards and regulations where relevant.

5.2.3 Issues Associated with Confirming and Changing Grid-Connected Inverter Settings

A subsequent issue that arose from the decision to change the frequency trip settings for inverters on the network was how to implement them. P&W does not own or operate the inverters and therefore does not have the direct control over them to implement the changes itself.

For the PV systems installed under the Solar City program, P&W worked with both the Alice Solar City project and their contracted PV installers to arrive at a solution which involved the PV installers progressively changing the inverter settings directly during the installers' 12-monthly service inspections of the PV systems (it is understood that most of the inverters on the Alice System need the settings to be changed directly at the inverter by the installer and that this cannot be done by remote control across many/all inverters). For the non-Solar-City PV systems P&W has required that for all existing systems the PV installers change the inverter frequency trip settings to the new values. However P&W does not currently have the resources to confirm this has been done. P&W is unsure how many inverters have had the new settings implemented and are concerned that a considerable portion of the PV capacity on the network still has the old settings.

This raises the issue of what level of knowledge and control the utility has over the PV systems connected to their network. P&W is of the view that it should be simpler and more efficient to change certain PV inverter settings if needed and that inverters should be required to have the capability for this to be done remotely and across many/all inverters at once (e.g. via software and communication links). Whether it is done directly by the utility or by the installer at the direction of utility is also an issue to be addressed. There is also the related question of how utilities can efficiently and effectively confirm whether inverter settings are in line with the utility's requirements and whether they should be able to interrogate the inverters directly. This is an issue P&W believes may increase in significance as PV penetration levels increase, and one that should be considered in future reviews of relevant standards and regulations for grid-connected inverters.

At the time of writing this report P&W has not experienced (or initiated) any further system frequency drop events of note below 49.9Hz in order to be able to determine the extent to which the PV power loss effect had been reduced by the request for installers to change the inverter frequency trip settings.

5.2.4 Summary

In summary P&W has experienced, identified and taken steps to address a PV grid integration issue which is specific to smaller autonomous electricity supply systems where system frequency operating limits are broader than for large interconnected networks. In doing so P&W has also identified that:

- Expanded frequency trip setting requirements should be applied to all PV grid-connected inverters in the Northern Territory.
- There is a need to resolve how utilities can efficiently and effectively confirm, and if necessary make changes to, grid-connected PV inverter settings such as frequency trip settings.

5.3 Small PV Fluctuations on the System Net Load Profile Due to Clouds

In the last year, due to the increased numbers and capacity of PV systems on the Alice network, P&W has begun to observe what it calls “fluctuations” or “ripples” on the system net load profile during sunny days with intermittent cloud cover. P&W says this is due to large clouds passing over Alice Springs impacting upon PV power output across the system and that the effect of this is now large enough to be observed on the system net load profile.

It is understood based on discussions with P&W that these fluctuations can be of the order of close to 1MW and of duration of the order of minutes.

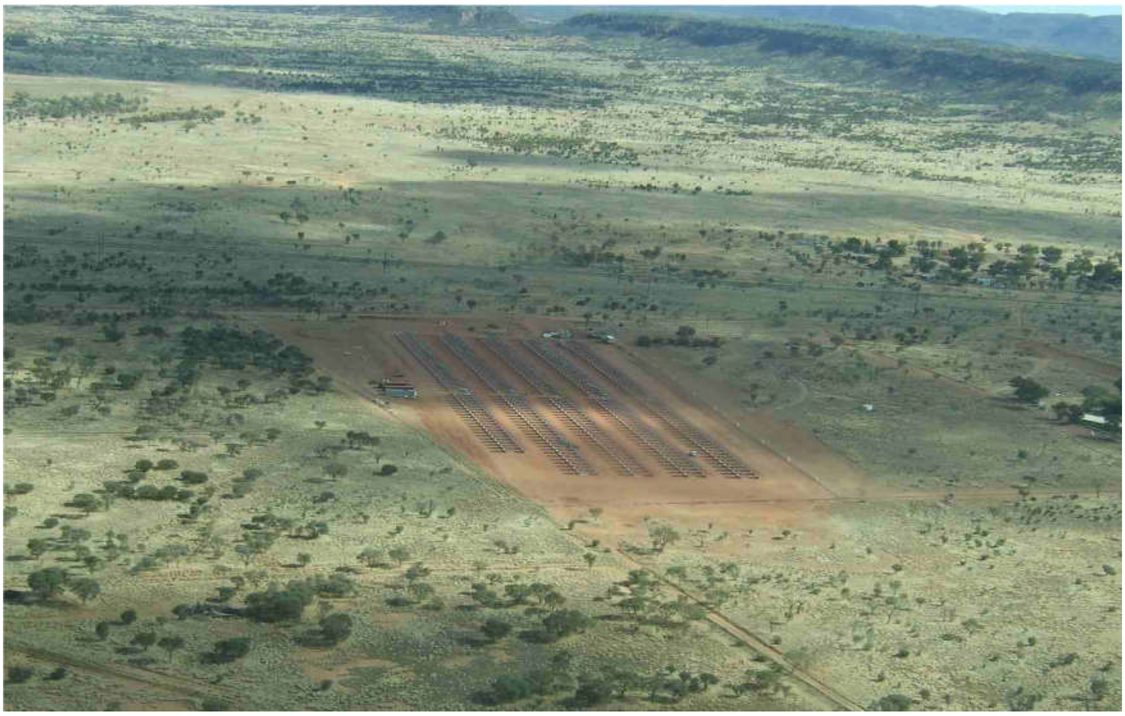
P&W says these fluctuations are currently having no material impact on system operation however it is something they will be keeping an eye on, particularly with the pending connection of the Uterne 1MW PV system, given it is a large single system which will be more directly affected by clouds than the smaller distributed PV systems.

The key implication of such fluctuations for the network - particularly if they are to increase in the future with increased network PV capacity - is on the dynamics of the centralised generation system, and on spinning reserve requirements (i.e. the amount of immediately available spare generation capacity required to be available from running generators).

In terms of centralised generation system dynamics, if the system PV power falls or rises rapidly and significantly due to passing clouds (e.g. changes of the order of 1MW over seconds or minutes) then the central generation system needs to be able to rapidly vary it’s power output up or down accordingly. In the case of a requirement to ramp up there needs to be adequate spinning reserve available if more generators cannot be brought online in the timeframes required. As such the amount of PV capacity on the system can impact on spinning reserve requirements.

In general, adequate spinning reserve must be maintained at the central generation plant in order to be able to respond to situations such as:

- Rapid increases in load (for e.g. during early morning periods in Alice Springs, typically around 6am-9am);
- Generator failure or other generator operating problems;
- Other situations that may indirectly cause rapid loss of generation or rapid increases in net load (e.g. rapid loss of system PV power due to clouds passing over).



Aerial photo of the Uterne 1MW system under construction, showing clouds passing over the array (courtesy P&W)

The level of spinning reserve required at any point in time will vary depending upon the actual likelihood of any of the above situations occurring (for e.g. PV power loss is not an issue at night; similarly rapid load rises are unlikely late at night). As an indicative figure, it is understood that the average spinning reserve level on the Alice network is normally of the order of 5MW. This is commonly provided by maintaining adequate available capacity across several generators running at high loading levels (e.g. 80%) rather than having one dedicated generator running at a low loading (e.g. 20%) in order to maximise generator operating efficiencies.

With the pending connection of the Uterne 1MW system, the level of spinning reserve required during the middle of the day will need to be reviewed by P&W. P&W will also be monitoring the potential effects of having an additional 1MW of PV power drop in or out of the system over a period of potentially seconds, and the potential effect of this on the gas-fired generators.

It is noted that P&W has not observed any other effects on the network of PV power fluctuation due to clouds (e.g. localised voltage effects).

5.4 LV Distribution System Voltage Management

Maintaining customers' supply voltage within acceptable limits is a core obligation of electricity distribution authorities. Achieving this is an ongoing management activity for utilities as voltage levels are affected by a range of factors including the design and method of operation of the distribution system, customer loads, and now also by decentralised generation such as PV systems.

A rooftop PV system connected to the Alice network.

PV systems installed on distribution networks introduce their own particular characteristics that can affect distribution system voltage levels, so their integration into networks needs to be carefully managed by utilities. In particular, PV systems act to reduce the load drawn from the network by customers and can also cause power to flow back into the network. These effects result in a higher line voltage that would otherwise have been the case in the absence of the PV system. PV power output also fluctuates with sunshine levels which in turn can cause fluctuations in system voltage, just as fluctuations in customer loads can cause fluctuations in system voltage. As PV penetration levels on a network increase, a risk is that system voltage limits may be exceeded, as they can be if customer loads significantly increase or decrease. Distribution utilities therefore need to monitor and manage PV penetration levels on their network.

P&W is presently required to supply voltage to LV customers within the limits shown in Table 9 below. For reference this table also contains P&W's requirements for upper and lower voltage trip settings for grid-connected PV inverters. As described further below, P&W is planning to change its LV system nominal voltage from 240V to 230V in line with a general movement within the Australian electricity supply industry towards the 230V nominal LV supply voltage.

P&W LV System Voltage Requirements	Value
LV System Nominal Voltage	240V
LV Customer Upper Voltage Limit (230V + 10%)	253V
LV Customer Lower Voltage Limit (230V - 6%)	216V
Grid-connected PV Inverter Over-voltage Trip Setting	253V
Grid-connected PV Inverter Under-voltage Trip Setting	210V

Table 9: P&W LV System Voltage Limits for Customer Supply and Grid-Connected PV Inverters

P&W has stated that to date, despite a significant increase in the number of PV systems connected to the Alice network, they have not yet experienced PV-related voltage issues of any note as there has not been a high enough concentration of PV system penetration in any one area to cause such problems.

P&W is however well aware of PV system penetration effects on LV system voltage being a key area of risk, and will continue to actively monitor LV voltage levels in high PV penetration areas of the network with this in mind.

Further, in order to obtain a better understanding of this issue P&W has recently commenced a project, in conjunction with the Centre for Renewable Energy[16] (CRE) at Charles Darwin University, to investigate the potential effects of high levels of PV system penetration on LV system voltage on the Alice network. This study will focus on a particular residential street in Alice Springs which has the highest concentration of PV systems on the Alice network (refer to the large red dot on the diagram in **Figure 4**).

Other actions P&W plans to undertake to better understand and/or manage potential LV voltage effects include the following:

- P&W is currently assessing the feasibility of using smart-meters installed at customers' premises containing PV systems to log customer voltage data along with the other parameters they presently log for billing purposes (i.e. power and energy consumption data) and remotely collect and collate this information as part of the normal metering/billing process in order to provide more comprehensive and ongoing customer voltage data for further analysis. It is noted that this is likely to only apply to larger PV systems (e.g. >40kWp, which must have smart-meters installed) or PV systems installed under the Solar City program (which required smart meters be installed), as there are no requirements on other PV systems to have smart-meters installed.
- P&W also plans to put meters on selected distribution transformers which have high levels of PV system penetration in order to monitor LV system voltage levels as well as other relevant parameters such as current and power flows in order to get a better understanding of PV penetration impacts at the distribution transformer level.
- P&W has a broader plan to reduce the nominal system LV supply voltage in the Northern Territory from 240V to 230V in line with a general move by the Australian electricity supply industry to change to a 230V nominal LV supply voltage. This will also help reduce the likelihood of PV-induced voltage excursions above the LV system upper voltage limit as network LV voltage operational settings will generally be lowered to target the new 230V nominal voltage setting, while the upper voltage limit will remain at 253V. This gives an additional 10V leeway between the new nominal voltage and the upper limit. P&W considers the need to manage PV-related LV voltage effects an additional incentive to complete this move to a 230V nominal LV voltage sooner rather than later.

In summary, despite significant increases in PV penetration on the Alice Network P&W has not experienced PV-related LV voltage management issues of concern to date. However they are aware this is an issue that needs to be carefully monitored and managed, particularly if PV penetrations continue to increase as they are expected to, and have initiated specific actions to this effect.

5.5 Reactive Power Management

5.5.1 Reactive Power in Electricity Supply Networks and Grid-connected PV Systems

Most loads on AC power networks require reactive power as well as real power. This reactive power must be supplied by the network, or if not, via another reactive power source connected near to the load such as a power factor correction unit or an embedded generator (e.g. a PV system inverter - discussed further below).

The proportion of reactive power relative to real power required by the load at any point on the network can be described by the load's power factor. Most electricity authorities require customers to maintain their power factor above a minimum level, typically around 0.8, although this varies by utility and can also

[16] www.cdu.edu.au/engit/renewable_energy/index.html

depend upon customer type and the specific customer or network situation at hand. The utility doesn't want lower power factors than this on the network because it means significant amounts of reactive power must be supplied which is inefficient and costly, and can cause a range of network problems including increased network power losses and voltage regulation issues.

For this reason many commercial and industrial electricity tariffs contain a component to also encourage good customer power factor (for e.g. a $/kVA charge) and help reduce network reactive power requirements. It is noted that residential tariffs do not contain reactive power-related components (considered to date to be unnecessary, complex and expensive) and are almost always based purely on energy consumption (i.e. $/kWh). It is noted that the emergence of more cost-effective electronic residential metering that can also measure reactive power may change this.

As with network LV system voltage management discussed in the previous section, the management of network reactive power is an ongoing activity for utilities as reactive power management is affected by a range of factors including the design and operation of the generation, transmission and distribution systems, and customer loads. It is also noted that the management of reactive power on electricity networks is also related to network voltage and power losses as each are electrically related.

Grid-connected PV systems have particular reactive power characteristics and capabilities, primarily determined by the PV system inverter and its control system. These can be viewed either positively or negatively depending upon the inverter's capabilities and how it operates on the network. For example, inverters previously have typically only been capable of injecting real power into the network, whereas more recent inverters are capable of providing a degree of reactive power support to both loads and the network itself. The ability to utilise the reactive power support capability of grid-connected inverters is now primarily dependent upon the rules and regulations governing the operation of inverters on the network in question.

As an example of reactive power management issues relating to a grid-connected PV system, consider the case of a PV system installed at a commercial premises and having a PV power output capacity similar to the site's midday power demand (quite a feasible situation). Then, if the PV system's inverter were set to provide only real power (and no reactive power) the customer's resulting "net" power demand supplied by the network in the middle of a sunny day could consist largely or entirely of reactive power. If this type of situation were to become significant on the network then it could potentially create reactive power supply related problems for the network, particularly during strong sunny periods. Alternatively, if the PV system's inverter provided adequate reactive power support, this should not be an issue. However it is noted that increasing the reactive power supplied by the inverter causes the real power supplied to reduce which, depending upon the customer's tariff, may not necessarily be of financial benefit to the customer.

There is also potential for PV system inverters to be used to provide reactive power to support network voltage and reduce power losses (as these are all inter-related) however this is not discussed further here.

5.5.2 Reactive Power Management with PV Systems on the Alice Springs Network

With the exception of very large PV systems (e.g. >500kW) P&W presently requires that grid-connected PV systems in the Northern Territory only supply real power to the network regardless of the inverter's reactive power capabilities. This is to the benefit of most PV customers as it means the maximum amount of the PV array's power output is used to generate real power and therefore electrical energy, upon which most customer's tariff's are based (and hence having the maximum effect in reducing their electricity bill), as opposed to some of the PV array's power being used to produce reactive power which is not factored into most customer's tariffs, and which does not produce real electrical energy. P&W is aware of the reactive power support capabilities of many inverters presently available on the market and have been evaluating the reactive power management issue particularly with regard to larger PV systems (discussed further below).

To date P&W has had no specific problems of note with reactive power management in relation to PV system penetration on the Alice network. However as with the LV system voltage management issue previously discussed this is something they are aware of and are assessing in terms of ongoing management. Particular activities they are undertaking in relation to this are:

- P&W has made it a requirement of the power purchase agreement for the Uterne 1MW PV system that reactive power is to be provided by the Uterne system as well as real power and that the mix of the two shall be broadly be in line with the Alice system's average load power factor.
- P&W is interested in the potential for PV systems that utilise larger (e.g. 3-phase) inverters to provide reactive power support. P&W is currently investigating this, however it is likely to only apply in the foreseeable future to certain larger power producers or commercial or industrial customers installing PV systems (e.g. 100kW+), and then on a case-by-case basis.
- P&W has required a 100kW PV system to have a 60 kVAr power factor correction unit installed to keep the power customer's power factor above 0.85. P&W notes that the cost for this unit was approximately $6,000.
- P&W is considering the potential for residential PV systems to provide reactive power support, however at present there are no plans to do this in the foreseeable future.
- In relation to the above items, P&W is looking more closely at the costs and value of PV power on their networks, and related tariff structures. One issue being considered is whether or not it should incorporate into the tariff structure for PV customers a component that charges them for the additional reactive power required to be supplied by the network (e.g. beyond a normally acceptable power factor value) where the PV system cannot provide it itself.
- Another related option P&W is considering is a kVAh basis for metering (rather than simple kWh) now that economic electronic metering is available. This will reward good power factor performance.

In summary, P&W has not yet experienced any technical issues of concern on the Alice network to date regarding reactive power management in relation to PV system penetration. However reactive power management in relation to PV systems is an issue it is aware of and is in the process of reviewing. In particular it has made reactive power provision a specific requirement of the power purchase agreement for the new Uterne 1MW PV system and is also considering reactive power support requirements for large PV systems on a case-by-case basis.

5.6 Other Potential High PV Penetration Effects

This section discusses several other high PV penetration effects that can potentially be experienced in electricity supply networks but which have not been encountered in any significant or material way by P&W on the Alice Springs network and have not been identified as a concern. The main aim in discussing them here is to describe what they are, identify that they have been considered in this case study and also by P&W, and explain why they are not currently considered an issue by P&W on the Alice Springs network.

5.6.1 Reverse Power Flow

(i) Reverse Power Flow in Electricity Supply Systems

Historically, most electricity supply systems have been designed for power flow primarily in one direction – from centralised power stations through transmission and distribution networks to customer loads. The majority of the elements of these networks have therefore been designed with this uni-directional power flow in mind.

Increased penetration of distributed generation on distribution networks (e.g. PV systems) can result in power flowing in the reverse direction, from the "customer" back into the network. Depending upon the level of penetration of distributed power this "reverse" power flow can potentially occur at various levels of the supply system including at: the customer's connection point; the distribution transformer; high voltage distribution feeders; distribution zone substations; and even at the sub-transmission or transmission levels.

Issues that can potentially arise and may need to be managed as a result of such reverse power flows can include:

- Metering/monitoring devices and systems not currently existing at appropriate points on the network (e.g. distribution transformers) to identify the existence and degree of reverse power flow.
- Existing metering/monitoring devices and systems not having been configured or designed to register the existence and degree of reverse power flow at that point on the network (e.g. on feeders or at zone substations).
- Network fault protection equipment not having been properly configured or designed to identify and respond to faults on sections of the network where reverse power flow exists.
- Other potential operational or safety-related issues such as utility network equipment which is not designed for reverse power flow not operating correctly, or suffering damage or failure due to reverse power flow situations.

Having said this, many elements of electricity supply networks operate under conditions of power flow in both directions so it is largely an issue of appropriate design and operation practices for the situation at hand.

The Alice Springs Lovegrove Zone Substation.

(ii) Reverse Power Flow due to PV Systems on the Alice Springs Network

As previously described in Section 4.4 P&W has stated that there are currently no situations where reverse power flow occurs on the Alice network at the distribution transformer level or above due to PV systems. There will be situations where reverse power flow occurs at certain customer connection points (i.e. with a PV system installed) or on parts of LV distribution circuits where there are high penetrations of PV power. However P&W does not currently consider this an issue of any significance in itself for the normal operation of the network. It is noted that this may have implications for LV system voltage management or reactive power management, however these have already been discussed earlier.

Further, P&W is of the view that the PV power penetration levels driving these reverse power flows are not yet significant enough to have any undue effect on network fault protection equipment operation or other network equipment.

P&W is also undertaking the following previously-mentioned activities which it will use to continue to monitor and assess PV-related reverse power flow on the network:

- Installation of meters (for current/voltage/power measurement) at selected distribution transformers with high levels of PV system penetration.
- Initiation of a study in conjunction with the Centre for Renewable Energy at Charles Darwin University which will look at the effects of high PV system penetration on LV system voltage on a street section of the Alice LV system with high numbers of PV systems. This study will also look at levels of reverse power flow on that section.
- Monitor the operation of the pending Uterne 1MW PV system once connected. As mentioned previously this system will be connected to a feeder which currently supplies large amounts of power (>1MW) in both directions so any "reverse" power flow caused by the Uterne PV system should not be an issue for this feeder.

5.6.2 Network Fault Protection and PV System Islanding

Network fault protection equipment is designed and configured to identify and respond to a range of network fault situations. These can include supply lines being brought down (e.g. storms, accidents) and network equipment failing, among others. When a fault occurs generation may continue to feed the fault until it is detected and isolated by the protection equipment.

Grid-connected PV systems are generators and as such need to be accounted for in the network's fault protection system as they can potentially feed faults and affect the ability of network protection equipment to identify faults. PV inverters are designed to disconnect from the network if they identify that the grid supply has breached acceptable limits. However they cannot identify all network faults. These must be identified by the network protection equipment which also needs to factor in the presence of the PV systems on the network to be able to assess whether it is seeing a fault situation or not. This involves utilities managing network protection risks and settings accordingly based on PV penetration levels, and taking any action required.

P&W states that it has assessed the network protection systems on the Alice system with respect to the increased levels of PV system penetration and this is not presently an issue.

Another issue is whether it is possible for some PV inverters to continue to supply power to the network when the main grid supply is lost, particularly in a situation where there are many PV systems on the network. This should not occur due to design requirements of PV inverters but it is an issue still discussed. This is referred to as PV system "islanding" and is generally considered extremely unlikely.

P&W is not aware of any instances of PV system islanding on the Alice Springs network or on any other electricity supply networks it manages.

5.6.3 System Harmonics from PV Inverters

Grid-connected PV inverters can inject harmonics into the network. If system harmonics become large enough they cause network quality of supply problems that can affect certain loads and network equipment. Inverter harmonic injection has become less of an issue with modern inverters, although lower quality inverters can still cause problems.

P&W states that harmonic injection from PV inverters is not an issue on the Alice Springs network. P&W measures system harmonic levels at certain points on the network and states that the prime concern with respect to harmonics is actually from switched-mode power supplies (in computer equipment) and not PV inverters. P&W is of the view that good quality inverters have primarily been installed on the Alice network and that is why there are no system harmonic issues relating to PV inverters.

6 FINDINGS

This section summarises the key outcomes of this Case Study by re-stating the Case Study aims then summarising the key outcomes from each of the main sections of the report. Areas for further investigation are outlined along with key next steps.

Aims of the Case Study

As stated in the Introduction, the primary aims of this case study were to identify and communicate P&W's key experiences to date with increasing levels of PV penetration on the Alice Springs electricity supply system from a technical perspective, and to identify areas that may require further investigation and/or study as per the aims of the IEA PVPS Task 14 program and the APVA/CEEM High PV Penetration Research Program of which this case study forms a part.

Case Study Approach

As outlined in Section 3 the Case Study has been undertaken by following a clear, open and systematic process to involve key Alice Springs PV stakeholders and in particular P&W. As such the Case Study is considered to represent a fair and informed presentation of the current status of PV integration on the Alice Springs network from a technical perspective.

The Alice Springs Electricity Supply System and PV Penetration Levels

A detailed description was provided in Section 4 of the Alice Springs electricity supply system, the PV systems connected, and PV penetration levels. Key aspects identified in this section included:

- The Alice Springs Electricity Supply system is a small autonomous network (or "small grid") supplying a population of around 30,000 people consisting of residential and commercial customers and with a load in the range 15MW to 55MW and averaging around 26MW.
- It is supplied by three centralised power generation stations consisting of a total of nineteen primarily gas-fired generators, with a network of HV sub-transmission and distribution feeders feeding an LV distribution system, all of which mainly supplies electricity to urban customers.
- As such the Alice supply system has particular operational characteristics that can be different to those of large interconnected electricity supply systems, due primarily to the fact that is has much fewer and smaller generators and loads and over a relatively small network. In particular the Alice system experiences a wider range of system operating frequencies both during normal system operation and in the case of system events.
- From a starting point of two grid-connected residential PV systems several years ago there has since been a significant increase in both the number and capacity of PV systems connected to the Alice network, driven by a number of factors including broader support mechanisms for PV in Australia as well as the Alice Solar City project in Alice Springs itself.
- As at the time of this report there were 528 PV systems connected with 2.1MWp of capacity. This includes 460 small residential PV systems, 39 commercial systems, 27 demonstration systems at a PV showcase facility, and 2 larger "iconic" PV systems.
- Existing PV penetration at the system level is estimated to be around 4% to 5% for peak PV power penetration (i.e. mid-day on sunny days) and 1.5% for total annual PV energy generation. Present PV penetration levels at the HV feeder level are generally insignificant relative to normal feeder operating loads. PV penetration levels at the LV distribution feeder level are also relatively low but could be up to 30% of distribution transformer load at peak PV power times on specific transformers with high numbers of PV systems. There is understood to be no instances yet of reverse power flow through a distribution transformer.

- The connection of the Uterne 1MW system in July this year will bring the total installed PV capacity to 3.1MWp. This will be by far the largest single PV system on the network and is estimated to increase the system-level PV penetration figures to around 6.5% to 8% (for peak PV power output) and 2.5% (for total annual PV energy produced) respectively. P&W intends to closely monitor the operation of the Uterne system on the network.

Key Experiences to Date with Increasing PV Penetration Levels

Section 5 identified and discussed in detail P&W key experiences to date with increasing PV penetration levels. These experiences can broadly be summarised as follows:

- The present levels of PV system penetration have not had any material impact on the safe and reliable operation of the network and are considered entirely manageable by P&W.
- P&W has experienced one particular technical issue of note relating to a large number of PV systems dropping out when the system frequency fell below 49.9Hz. This was due to the PV inverter low-frequency trip settings. While it did not impact on the network safety or reliability it was a cause of potential concern from a system stability point of view. Actions have been taken by P&W to remedy the situation by lowering their PV inverter low-frequency trip setting requirement to 46 Hz for future PV inverter connections, and similarly by requesting existing inverters be set to these settings by installers. This issue is considered by P&W to be resolved for future PV system connections however P&W believes there are still many PV inverters on the network with the original frequency trip settings.
- P&W has identified three “potential” PV penetration issues which are not presently causing any problems of note but may become more significant over time if PV penetration levels continue to increase. P&W has already flagged these for further investigation and assessment. They include the effects of fluctuations in PV power due to clouds (particularly on the centralised generation system and associated spinning reserve requirements), LV system voltage management (particularly voltage rise), and reactive power management.
- P&W has also considered a number of other “possible” PV penetration issues but do not consider these to be an issue on the Alice network at present or in the foreseeable future. However they intend to maintain a watching brief on these issues and any other possible PV penetration issues generally and review them with respect to the Alice network as required. These include reverse power flow, PV penetration impacts on network fault protection levels/equipment, PV system islanding, and harmonics from PV system inverters.

Areas for Further Investigation and/or Action

P&W recognises that, due to a range of driving forces, it is highly likely the number and overall capacity of PV systems connected to the Alice network will continue to increase over time and that P&W needs to be prepared for this. This will involve ensuring that potential PV penetration issues are identified and managed in advance and that system planning and operational decisions factor in the potential for significant future PV system integration.

This case study has identified a number of specific areas for potential further investigation including specific recommendations and suggested stakeholders to implement them. Details of these have been provided to P&W and other Alice Springs PV stakeholders separately. The recommendations include both utility-specific actions which P&W may wish to pursue itself and other actions relating to further investigation and/or research which could be undertaken in conjunction with other Alice PV stakeholders (e.g. Alice Solar City, CAT Projects) and relevant research groups (e.g. CDU Centre for Renewable Energy, UNSW Centre for Energy and Environment Markets, and the CSIRO).

The general areas identified for potential further investigation and/or action are listed below:

- Metering, Monitoring and Analysis;

- PV Power Fluctuations Due to Clouds (Intermittency)
- LV Distribution System Voltage Management
- Reactive Power Management
- Other Potential High PV Penetration Effects
- Inverter Capabilities and Requirements
- Network Planning and Operational Processes
- Knowledge and Skills Development
- Long-Term High PV Penetration Management Plan

Next Steps

As stated in the Introduction, the APVA and CEEM plan to undertake a further four PV penetration case studies on selected electricity grids in Australia. Following completion of these an overarching report will be compiled outlining the findings and it is intended this will be sent to the participants in each of the individual case studies.

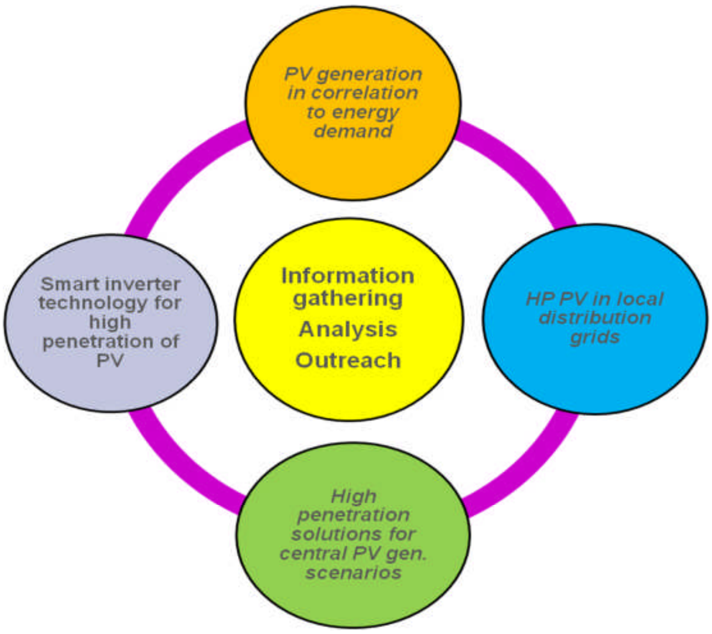
APPENDIX 1 - IEA PVPS TASK 14 AND FURTHER INFORMATION RESOURCES ON HIGH PV PENETRATION IN ELECTRICITY GRIDS

IEA PVPS TASK 14

The International Energy Agency (IEA) Photovoltaic Power Systems Programme (PVPS) conducts joint projects in the application of photovoltaic conversion of solar energy into electricity (see www.iea-pvps.org/). Currently seven research projects, so-called Tasks, are established within the IEA PVPS Programme: Tasks 1, 8, 9, 11, 12, 13 and 14.

The recently initiated (in 2010) IEA PVPS Task 14 (www.iea-pvps.org/index.php?id=58#c92) provides a forum for all IEA countries to share knowledge on the grid integration of PV in High Penetration scenarios. Currently, experts from research and industry in Australia, Austria, Canada, China, Denmark, France, Germany, Italy, Israel, Japan, Norway, Portugal, the U.S.A, Spain, Sweden and Switzerland are participating in Task 14.

The work to be undertaken in Task 14 will be in the areas shown in the diagram below.



Specific activities planned within each area include:

- Cross-cutting subtask: Information Gathering, Analysis and Outreach
  - Setup a repository for information and exchange of models.
  - Collect and analyse state of the art information about existing high penetration PV installations.
  - Gather a collection of existing modelling information.
  - Select and refine a set of pertinent cases for publication.
- Subtask 1: PV generation in correlation to energy demand
  - Development of Prediction Tools
  - Network driven demand side management.

- Subtask 2: High penetration PV in local distribution grids
    - Review of State-of-the-Art.
    - Optimized Reactive Power Balancing.
    - Optimized Active Power Control Strategies.
    - Change from Distribution to Supply Grids, and Dynamic Studies.
- Subtask 3: High penetration solutions for centralised PV generation scenarios
    - System-wide PV generation analysis and forecast.
    - Power system operation planning with PV integration.
    - Power system augmentation planning with PV integration.
- Subtask 4: Smart inverter technology for high penetration of PV
    - Opportunities for Smart PV inverters in High-Penetration scenarios.
    - Technical capabilities and Inverter Topologies.
    - Remote control and communication for Smart Inverters.

Further High PV Penetration Information Resources

The following is a selection of further information resources on the integration of high levels of PV penetration into electricity grids.

International

- IEA PVPS Task 14 High PV Penetration Workshop Presentations (Colorado, USA, Dec 2010; Portugal, May 2011):
    - http://www.iea-pvps.org/index.php?id=9&tx_damfrontend_pi1[setCatList]=61-85
- NREL (USA) Solar Energy Systems Integration Program – contains various High PV Penetration resources including presentations from a number of US stakeholder High PV Penetration workshops:
    - http://www.nrel.gov/eis/renewable_energy_integration.html
- US Department of Energy Systems Integration for Solar Technologies Program – contains various information and resources on High PV Integration activities in the US:
    - http://www1.eere.energy.gov/solar/systems_integration_program.html
    - https://solarhighpen.energy.gov/

Australia

- Energy Networks of Australia (ENA) Report 2011 - *Impacts and Benefits of Embedded Generation in Australian Electricity Generation Networks*:
    - http://www.ena.asn.au/