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GSES global sustainable energy solutions

Integration of Solar Power in Small Grids

Geoff Stapleton

Training • Consulting • Engineering • Publications

Background and Acknowledgments

The Australian Solar Institute (part of Australian Government) has funded the:

- Australian PV Association (APVA)

and

- Centre for Energy and Environmental Markets (CEEM) located within the University of New South Wales (UNSW)

To undertake studies of High PV penetration on grids.

- GSES was given permission to do this presentation. Most has been prepared by Dr Iain MacGill (UNSW) the Project Manager.

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Potential Australian High PV Case Studies

- Alice Springs Solar City – *Case study now released*
  - Regional (50MW) grid with gas-fired generation
- Carnarvon – *Case study now released*
- Townsville Solar City (Magnetic Island)
  - PV with major demand management initiative
  - Likely 2012
- Newington, Sydney
- Blacktown Solar City
  - Likely 2012

Solar City locations

Case study process – stakeholder engagement

- System questionnaire
  - collect and collate high-level information on:
    - the electricity supply system;
    - photovoltaic systems connected to the network;
    - general experiences being encountered with high levels of PV penetration on the network;
    - specific experiences being encountered with high levels of PV penetration on the network;
  - use the questionnaire as a basis for discussion with key stakeholders, and to identify specific high PV penetration areas/issues to focus on in more detail.”
- Possible feeder level surveys
- Site visits, stakeholder meetings

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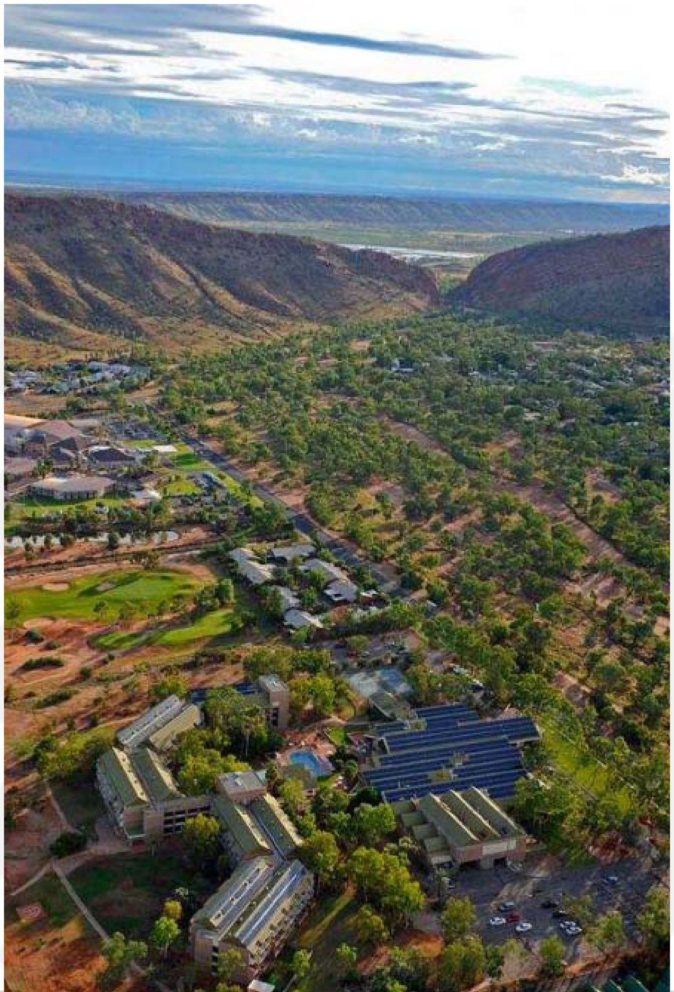
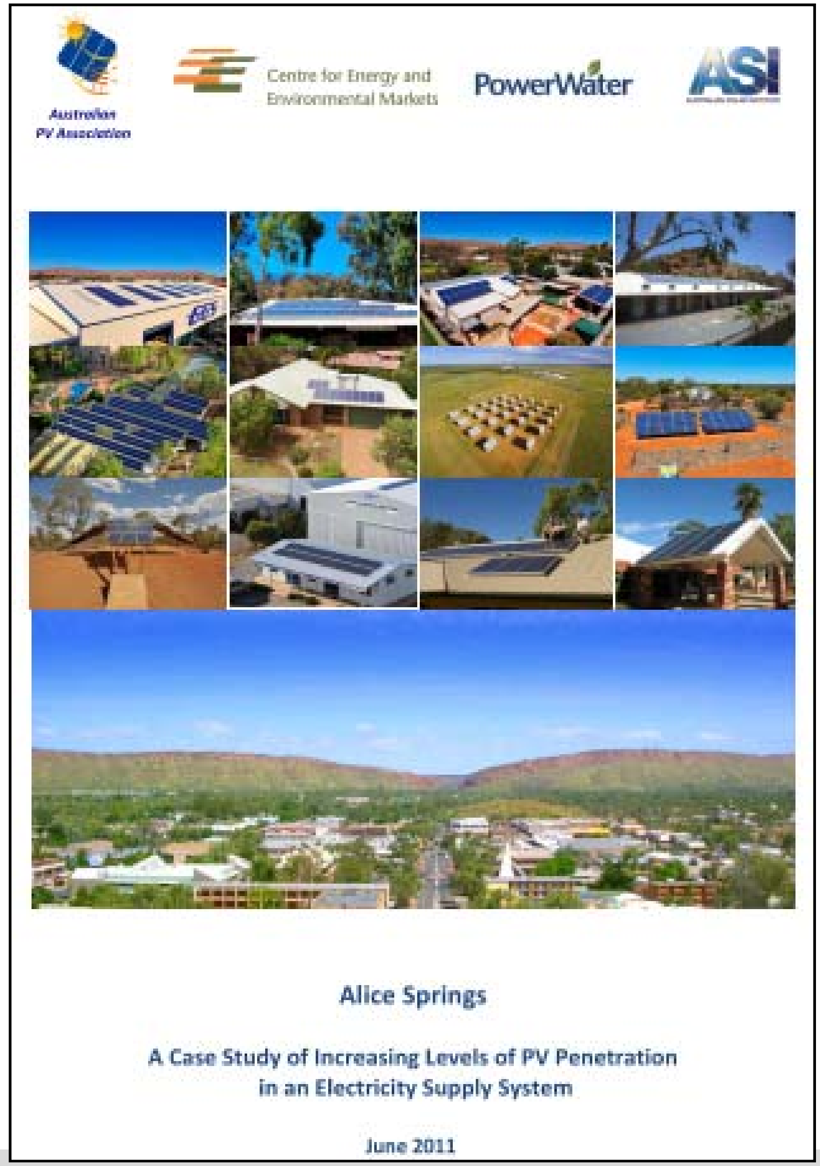
Alice Springs Case Study





Some recent 'high PV penetration' developments in Australia

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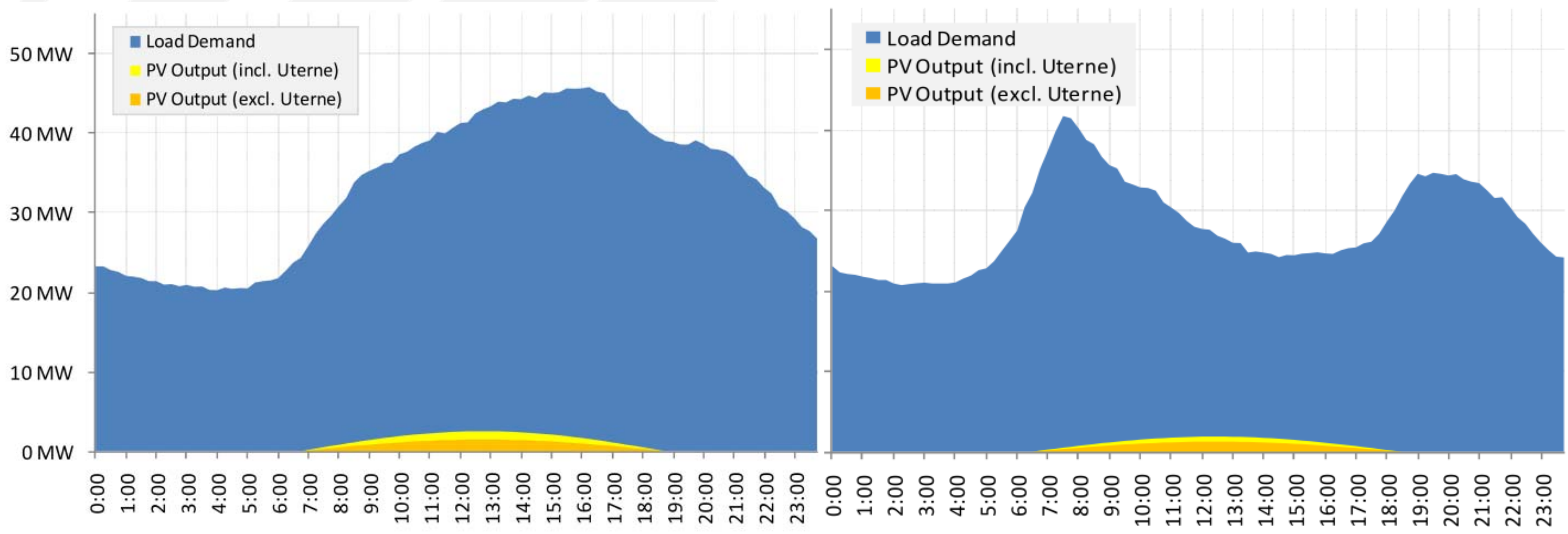
Penetration and profiles

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)

Typical Summer & winter profiles



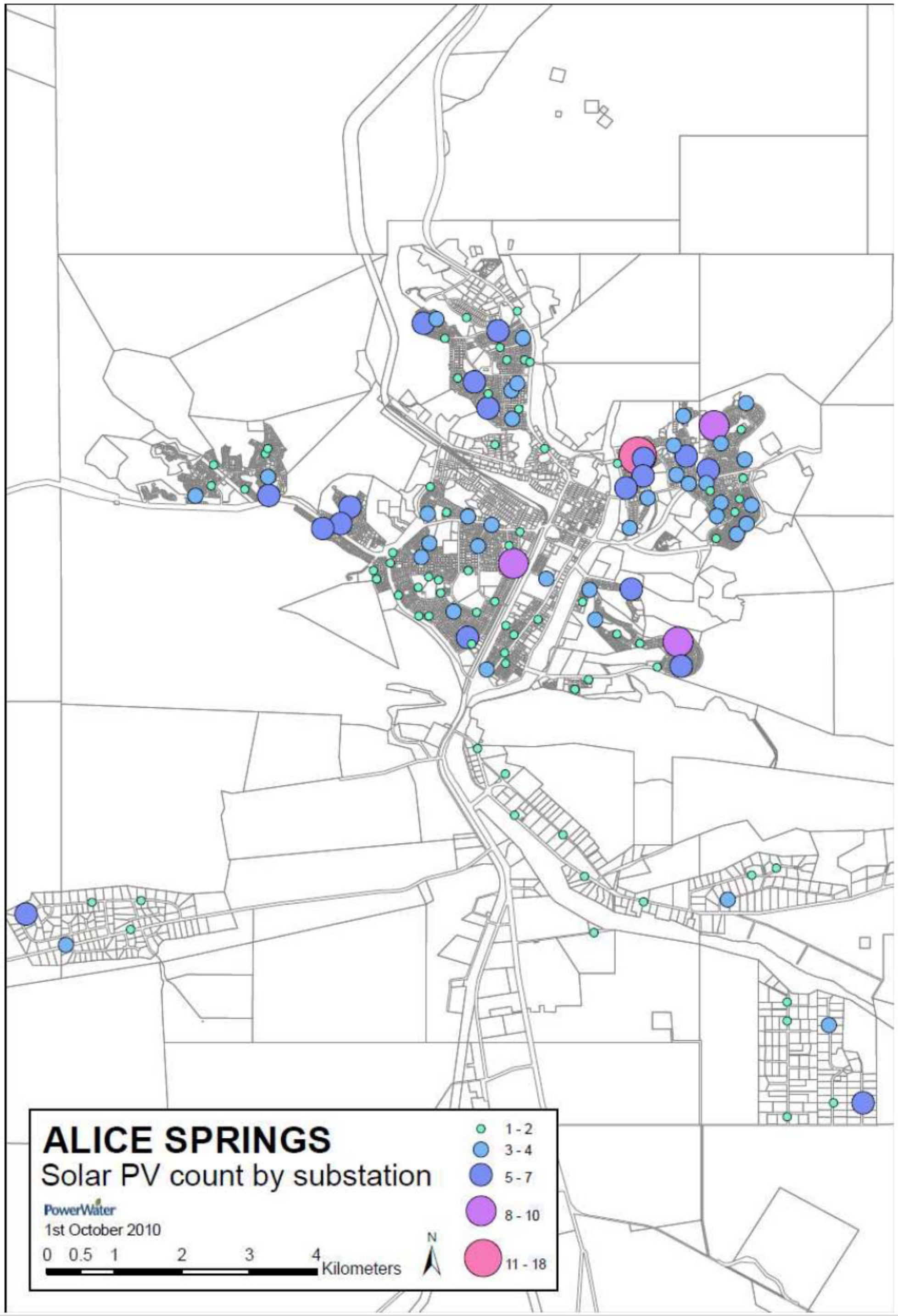
Specific network issues

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%

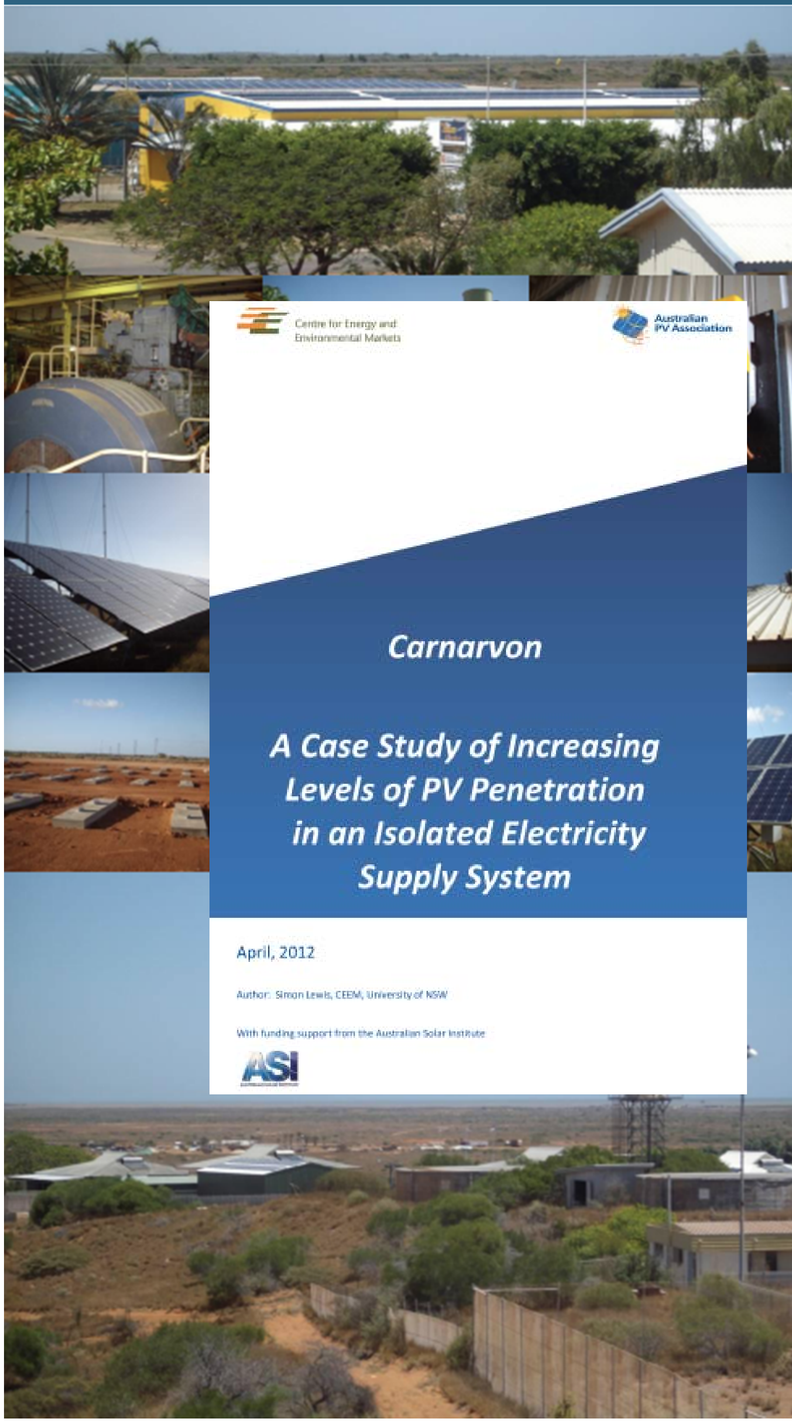
Indicative figures for Alice network feeder with highest PV penetration (Uter

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%

Indicative figures for distribution transformer with highest PV per



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).



Carnarvon Case Study

- Isolated 11.5MW gas/diesel grid
- 1.1MW of distributed PV capacity installed, 300kW utility system
- PV integration challenges
  - Local Integrated Utility, Horizon Power imposed hosting capacity limit of 1.15MW distributed PV, 2011
- *Case study with Horizon Power completed in April 2012*

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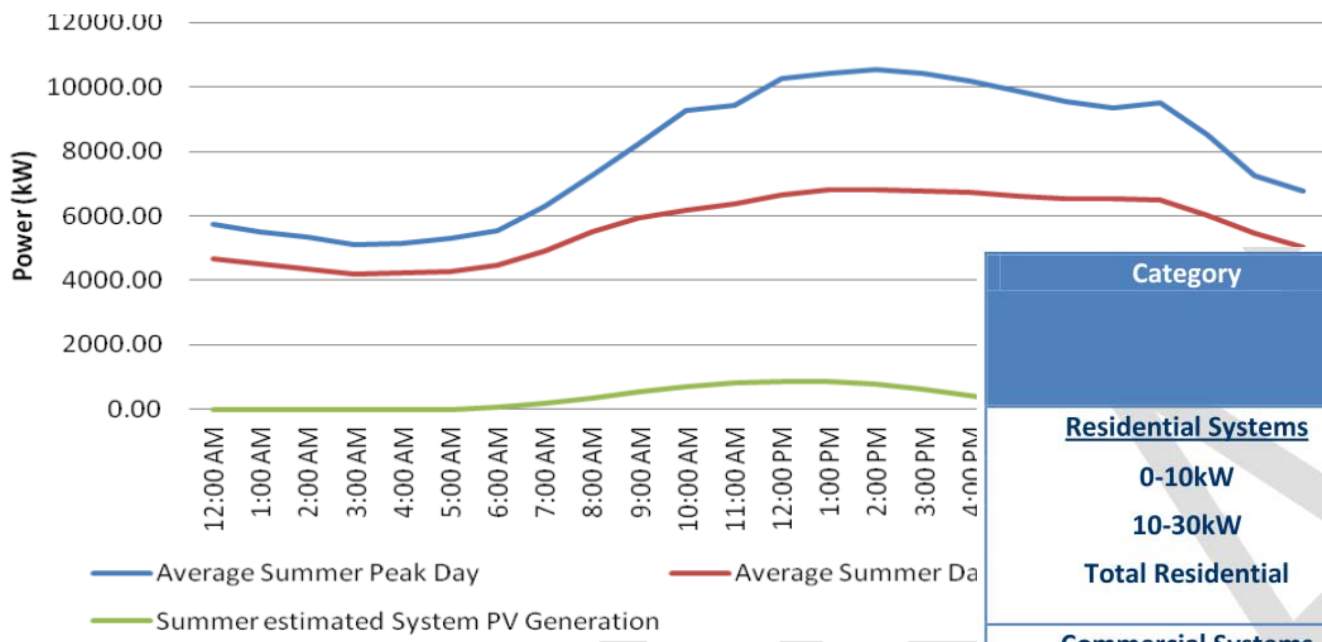

Figure 6: Carnarvon average peak day and average load profile in summer 2011 with estimated aggregate PV system output

Category	#	Nominal Capacity (kWp)	% of installed capacity
Residential Systems			
0-10kW	89	448	41
10-30kW	38	577	53
Total Residential	127	1025	94
Commercial Systems			
Total Commercial	1	67	6
Currently Installed PV Systems	128	1092	100

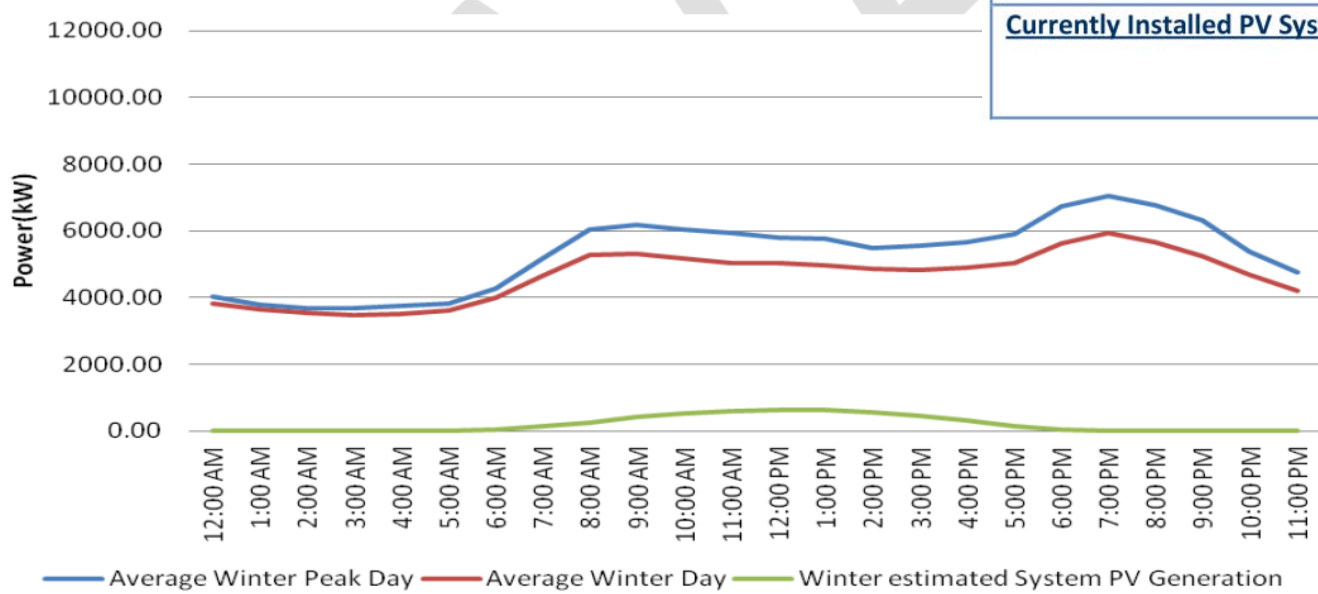

Figure 7: Carnarvon average peak day and average load profile in winter over the period 2006-2011 with estimated aggregate PV system output [8]

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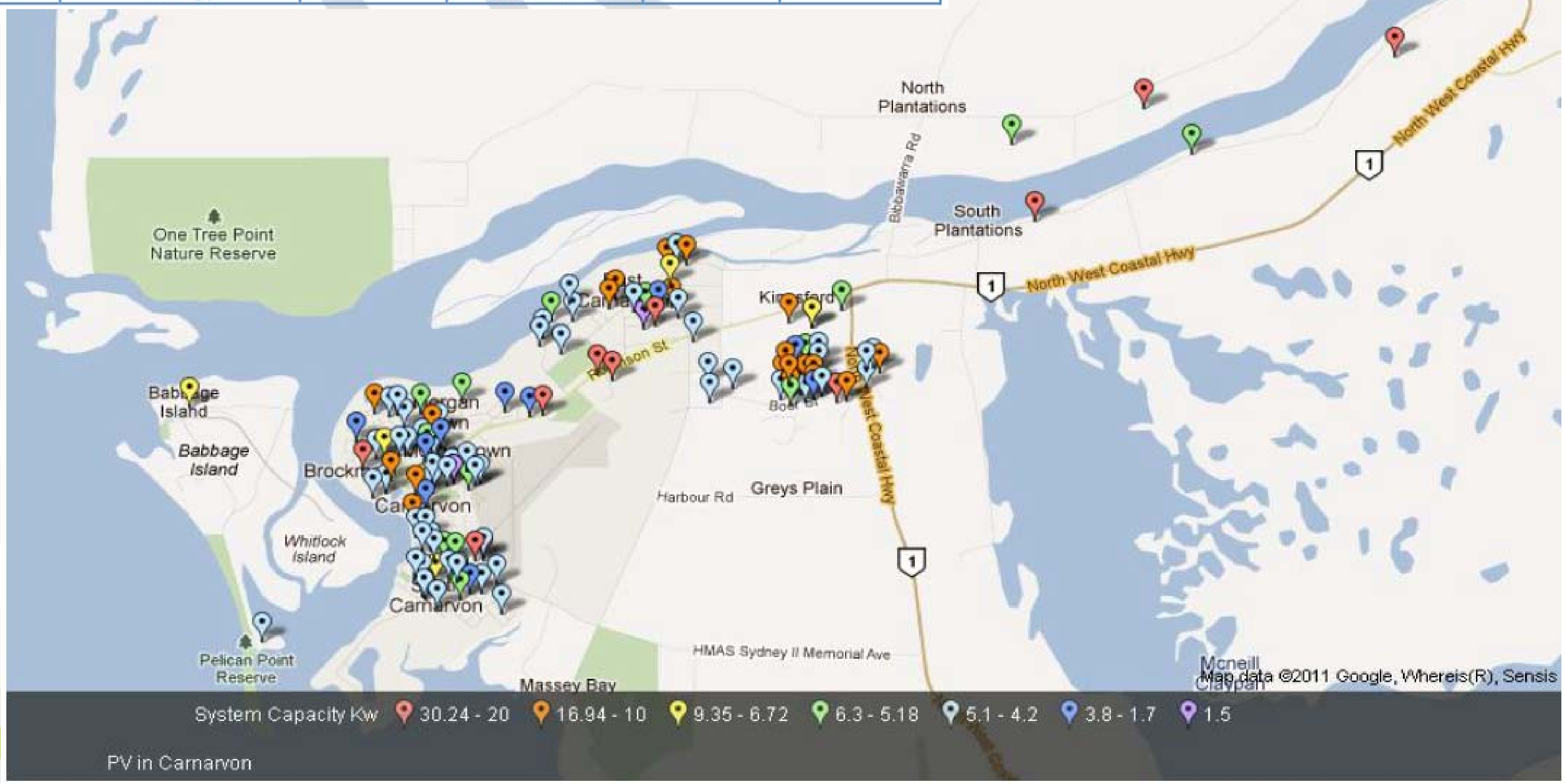
PV system deployment

PV Penetration Measure	PV Measure	Estimated Value	System Measure	Value	% PV Pen.
PV Capacity Penetration	Installed Nominal PV Capacity	1087 kWp	Peak Load	11560 kW	9%
PV Peak Power Penetration - Summer	Est. Summer Midday PV Peak Power	899 kW	Ave. Summer Midday Load Demand	6842 kW	13%
PV Peak Power Penetration - Winter	Est. Winter Midday PV Peak Power	651 kW	Ave. Winter Midday Load Demand	5000 kW	13%
PV Peak Power Penetration - Average	Est. Average Midday PV Peak Power	775 kW	Average Midday Load Demand	5921 kW	13%
PV Annual Energy Penetration	Est. Annual PV Energy	1.5 GWh	Annual Gross System Load	49 GWh	3%



Dx feeders

22kV Feeders	Feeder Rating (kW)	Nominal PV System capacity (kWp)	% of Feeder Cap	Number of PV systems
CRN 502.0 SOUTH RIVER FEEDER	5716	467	8%	48
CRN 504.0 TOWN FEEDER	5716	183	3%	29
CRN 509.0 NORTH RIVER FEEDER	5716	155	3%	11
CRN 510.0 BABBAGE ISLAND FEEDER	5716	129	2%	16
CRN 507.0 SOUTH CARNARVON FEEDER	5716	123	2%	23

Table 8: PV distribution on 22kV feeders in Carnarvon

Feeder rating	5716 kW
Nominal PV system capacity on feeder	467 kWp
Nominal PV capacity penetration	8%
Estimated PV Peak Output	327 kW
Average Midday Load on feeder	1200 kW
Indicative PV peak power/load penetration	39%

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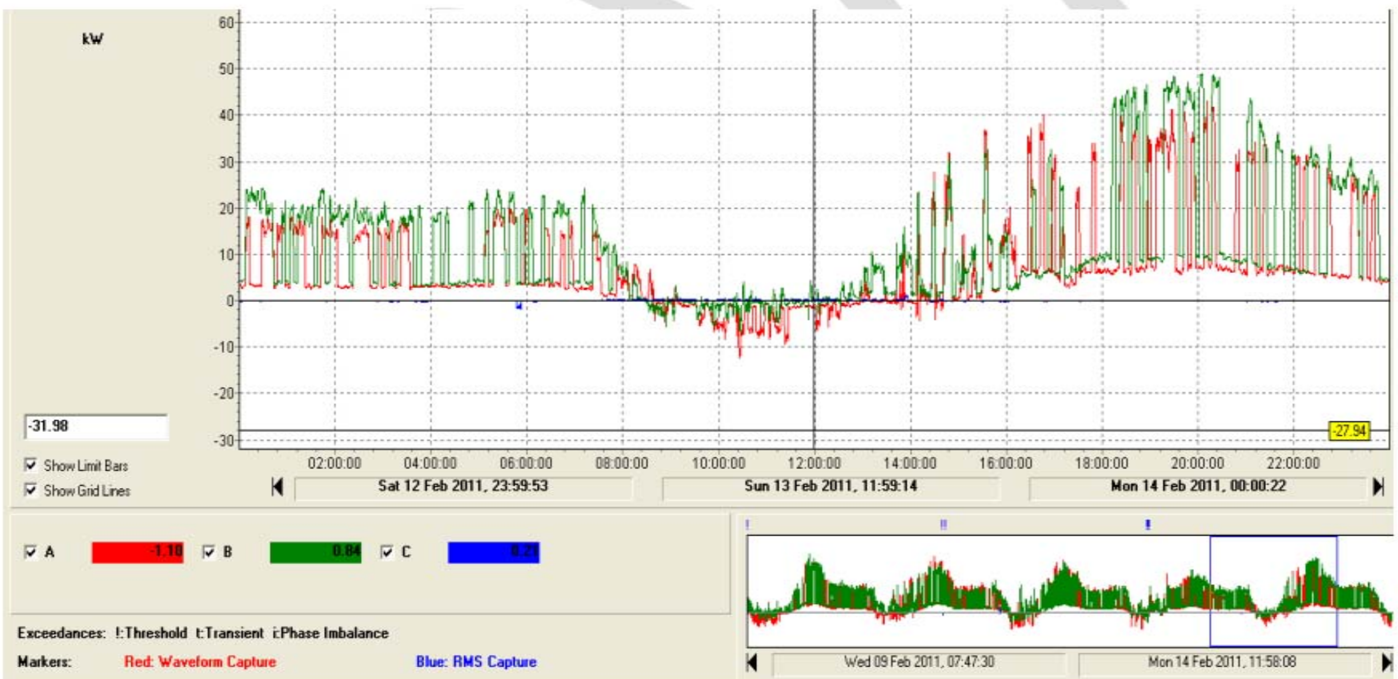
Distribution Transformer	Transformer Rating (kVA)	PV System nominal capacity (kWp)	PV Capacity as a % of Transformer Capacity
GIBSON	315	221	70%
NR122/6	63	40	63%
NR67/17/106	50	26	53%
NR129	63	30	48%
NR67/17/18	100	40	40 %
BILCICH	63	20	32%
CARNARVON PONY CLUB	200	60	30%
NR90A/4	100	29	29%
FINNERTY	100	29	29%
CARNARVON CHRISTIAN SCHOOL	100	21	21%
RICHARDSON	200	35	17%
NELSON	200	30	15%
ANGELO NORTH	200	30	15%
SILVER CITY	100	12	12%
MUNGULLAH	200	20	10%

Table 10: Top 15 highly penetrated distribution transformers in Carnarvon.



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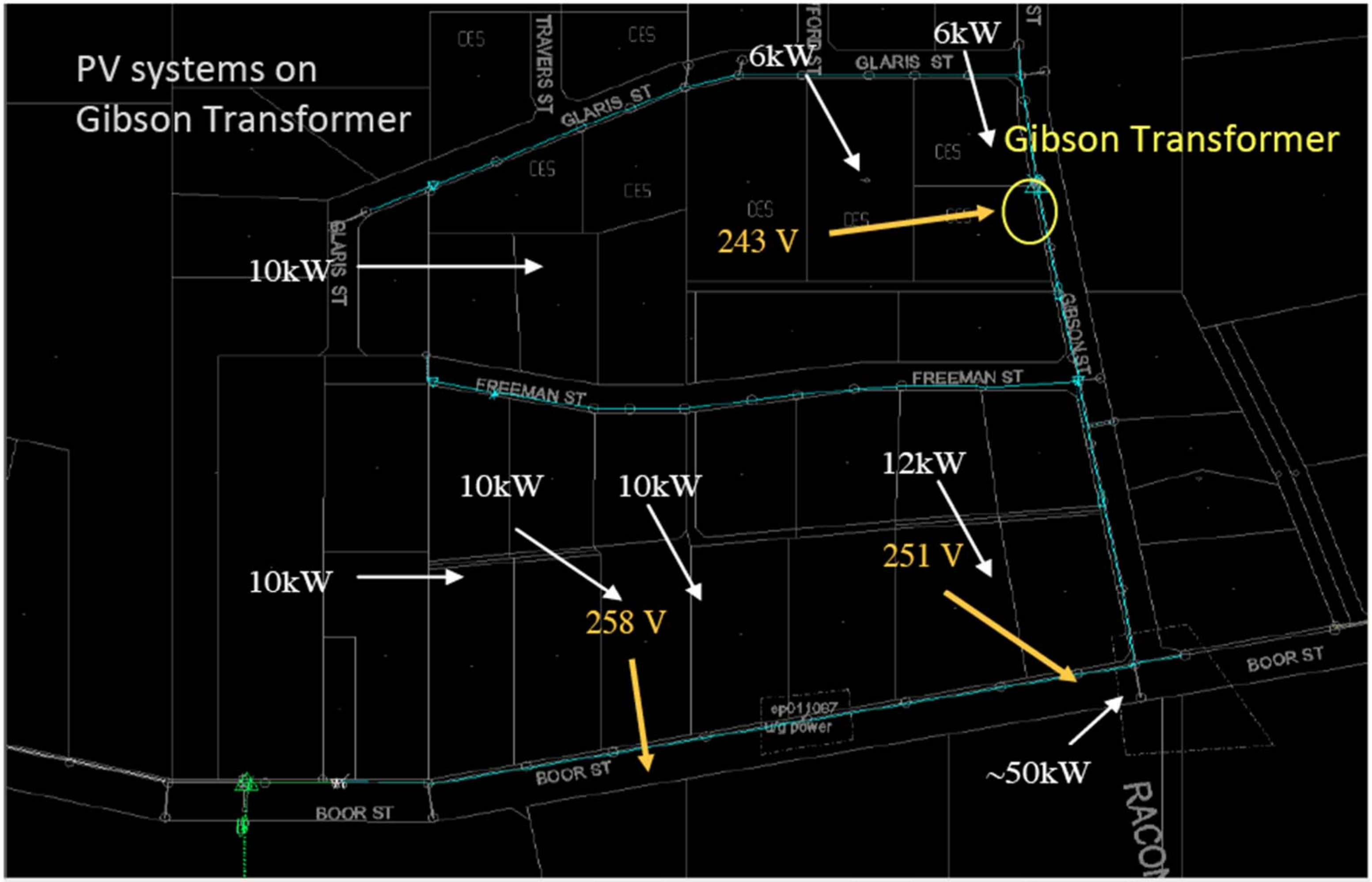
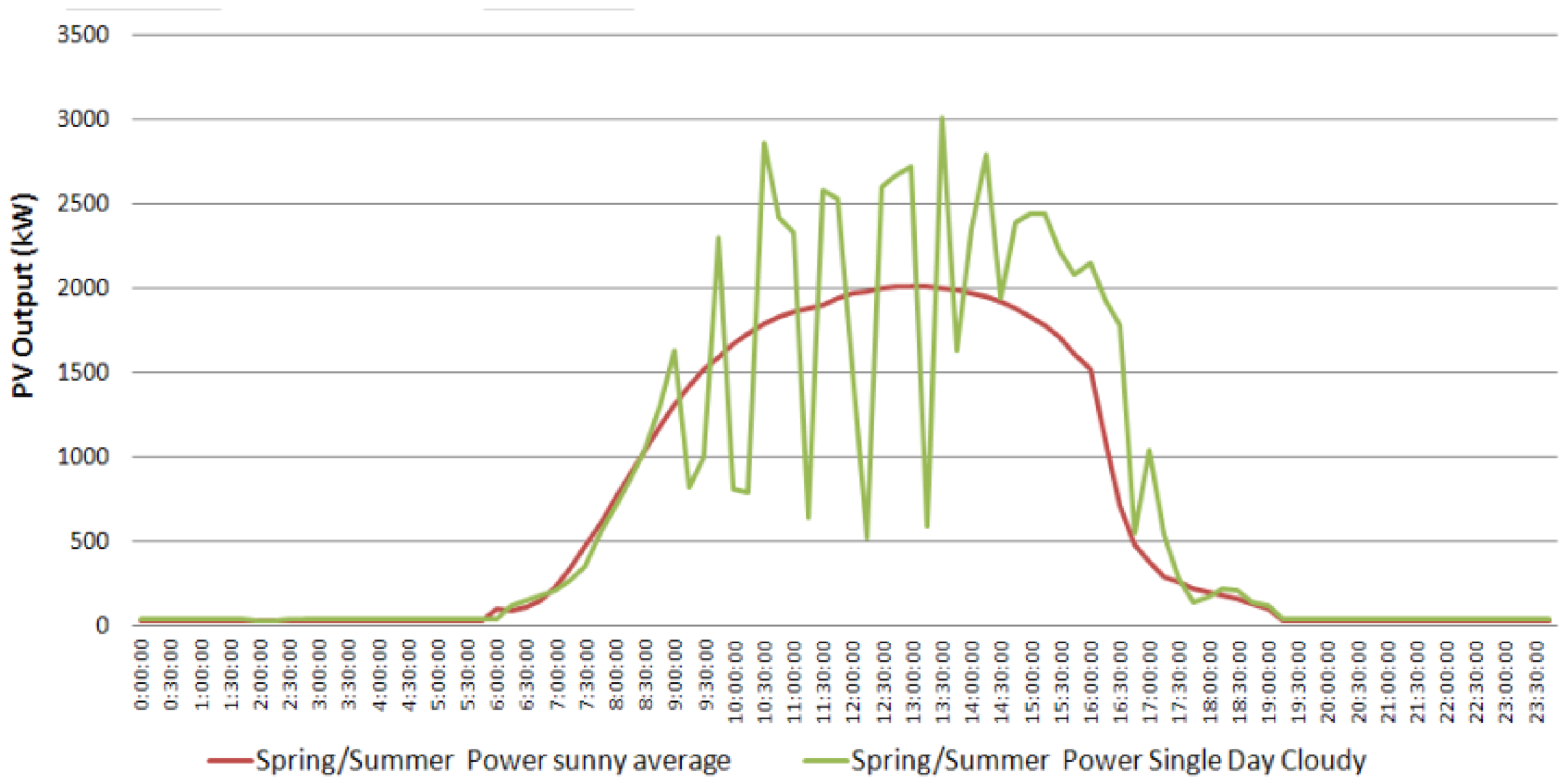
Voltage Rise/Phase Imbalance

- A range of solutions: eg. Tap changing



Cloud issues



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PV Penetration Experience	System wide or localised	Summary of the experience	Current/Proposed Management Strategies
PV systems impact on network stability due to inverter anti islanding protection detecting significant frequency deviations	System	There has been one recorded instance of multiple PV systems disconnecting due to a system wide frequency disturbance, resulting in additional load for the central generator to cover rapidly. A lack of standardisation amongst inverter anti islanding protection settings within AS4777 is also a concern.	Current: • Operating the network with sufficient spinning reserve to maintain the network if PV systems disconnect Trial: • Dispatchable load trial to increase system capability to respond to such disturbances Proposed: • Review of and PV inverter protection settings • Community solar farms with feed in management
Voltage rise in LV networks	Localised	There have been two recorded instances of significant LV network voltage rises have been identified in Carnarvon. Both problems have been resolved and the networks brought back within acceptable limits by reconfiguring the distribution transformer tap changer or line augmentations.	Current: • Rectification of phase imbalance with respect to both loads and PV system connections • Distribution transformer tap setting changes • Load shifting. • Network augmentation Trial: • Voltage regulation technology
PV system impacts on network stability due to cloud fluctuations	System	There have been no recorded system-wide fluctuations in load due to PV output variability. However significant fluctuations have been observed on a localised level. It is possible that with increased PV penetration this effect will be more evident on the supply network.	Current: • Operating the network with sufficient spinning reserve to maintain network stability with PV system fluctuations Trials: • Cloud sensor technology Proposed: • Further monitoring of system loads and PV generation

PV Penetration Experience	System wide or localised	Summary of the experience	Current/Proposed Management Strategies
Fires due to PV systems	Localised	There has been one reported instance of a fire caused by a PV system, made even more serious due to continued PV generation during the fire.	Current: • Management procedures are in place to ensure correct panel installations Proposed: • Extended fire fighter training • Change to problematic junction box designs.
PV system impact on planning strategies	System and localised	The variability of PV system output makes it difficult to plan for system peak loads as seen by the dispatchable generation. There is also a push for more commercial sized systems to connect to the network.	Current: • Work is being undertaken on forecasting the impact of PV systems on the network load levels Trial: • Horizon Power is trialling a feed in management system for a 300kW system installed Feb 2012.
System Islanding	System and Localised	Investigation has been undertaken into the possibility of network islanding due to PV systems and has concluded that it is extremely unlikely to occur in the current configuration.	Current: • LV network is earthed prior to work Proposed: • PV inverter protection settings are being reviewed in line with the impact on system stability and in line with studies mentioned above. Horizon Power would prefer that all inverters are set to a fixed value rather than be variable inside a range.

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PV Penetration Experience	System wide or localised	Summary of the experience	Current/Proposed Management Strategies
Reverse Power Flow	Localised	Currently PV systems are causing localised backfeeding through some distribution transformers but no significant effects are visible on the 22kV network.	Proposed: • Monitoring at higher PV system penetrations and a review of protection schemes is needed to prevent potential future problems
Reduction in generator fuel use	System	The current PV system generation in the network is resulting in a generator fuel saving which is equivalent to approximately 830 tonnes CO_2 per annum.	Benefit: • There is potentially significant value in such fuel savings depending on gas/diesel prices. The value of climate change abatement with PV is also potentially significant. By managing the spinning reserve strategy effectively and increasing the amount of PV in the system these benefits can be maximised.
Offsetting of peak summer loads with PV generation	System	PV generation generally corresponds well with the peak system loads implying possible deferral of network upgrades, and benefits can be further maximised by adjusting customer loads.	Benefit: • Analysis is currently being undertaken to estimate the amount that the PV systems can contribute to peak demand reduction in order to fully realise this benefit in terms of system planning

Reports are available from:

http://www.apva.org.au/reports

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- Monitoring of grid?

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HV feeders and each substation

Install smart meters (LV side of substations)

Having the data recording set at resolutions of 15 minutes.

Read/record: voltage, real power, reactive power, frequency, and THD.

If possible

(i)it is better to record individual harmonics. Sometimes the magnitude of the fundamental current is low due to backfeeding.

(ii) have it set that if the frequency varies by more than 1hz—eg reaches 49hz or 51 hz then resolutions is set at 1 minute for a period of time.

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Substations with PV connected

- Voltage and THD should be monitored (Use Polyloggers such as Powermonics)
- Monitor for 1 week (assuming sunny) –on the power lines near the actual systems and at various locations on the LV line from the substation.
- If it is not practical to monitor at different sections just monitor at the end of the LV feeder.
- The resolution of the data will depend on how frequently the data can be downloaded. If able to store 1 weeks data at 15 minute intervals that would be good-however it could also be set on trigger for certain scenarios—eg when voltage above certain value only.

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Locations of larger systems

- On some of the larger systems , say above 10kW monitor short term (again say 1 week) at the actual customers switchboard with the polyloggers.
- It would be good to monitor and record the generation of the system and if possible how much was being supplied onto grid and how much being used at the site.

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Data to be recorded for each substation

- Number of PV systems connected
- Size (kW) of each system
- Address/location of each system
- Which phase the systems are connected to.(appreciate that phase connection could change with time and not recorded).

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