PV INTEGRATION ON AUSTRALIAN DISTRIBUTION NETWORKS

Literature Review

By

The Australian PV Association

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About the Australian PV Association

The APVA is an association of companies, agencies, individuals and academics with an interest in photovoltaic solar electricity research, technology, manufacturing, systems, policies, programmes and projects. Our aim is:

to support the increased development and use of PV through targeted research, analyses and information sharing

Our work is intended to be apolitical and of use not only to our members but also to the general community. We focus on data analyses, independent and balanced information and collaborative research, both nationally and internationally.

Our reports, media releases and submissions can be found at: www.apva.org.au

Table of Contents

Figures

Tables

1 Introduction

In recent years there has been unprecedented growth in the Australian photovoltaic (PV) market, particularly in the deployment of residential grid-connected systems. As a result, situations of high-penetration PV, where additional efforts by Australian Network Service Providers may be necessary to integrate PV generation in an appropriate manner, are becoming increasingly common. This phenomenon presents both challenges and opportunities for such network businesses, broader electricity industry stakeholders and government policymakers.

The Australian Photovoltaic Association (APVA) was engaged by the Australian Solar Institute, now the Australian Renewable Energy Agency (ARENA) to investigate the associated impacts and contribute to Task 14 of the International Energy Agency’s Photovoltaic Power Systems programme (IEA PVPS): High PV Penetration in Electricity Grid. The University of NSW is leading this project for the APVA, with involvement from CSIRO, other APVA Members and utilities.

The Centre for Energy and Environmental Markets (CEEM) and the School of Photovoltaics and Renewable Energy Engineering (SPREE) (both of the University of NSW) conducted a survey of electricity distribution network service providers (DNSPs) across Australia. The survey focused on experiences with, and strategies for, dealing with high penetrations of solar PV. It was part of an international survey being undertaken by other countries participating in PVPS Task 14 and the findings will be published in a separate report.

This document served as the background document for the survey. A literature review was conducted of the publically-available information concerning PV integration on Australian distribution networks. Sections 2 and 3 provide an overview of electricity distribution in Australia, and the amount of PV that is currently installed. Sections 4, 5 and 6 respectively review the Australian standards, state-based regulations, and DNSP policies that apply to the connection of PV systems. Section 7 reviews a range of submissions and presentations that have been made by DNSPs to government enquiries and at industry conferences.

2 Overview of distribution network service providers

There are a total of sixteen distribution network service providers (DNSPs) in Australia. Thirteen companies supply customers in the National Electricity Market (NEM) that covers the eastern states, South Australia, and Tasmania. These are represented in Figure 1 (AER, 2012)

Figure 1 Electricity network areas in the National Electricity Market (AER, 2012)

The Victoria and South Australian DNSPs are privately owned and operated while all others are still State government-owned corporations. The ACT utility is a public-private partnership.

Table 1 provides some key statistics on the DNSPs.

Table 1 Key statistics for Australian distribution network service providers

State	Company	Ownership	Number of customers	Km Line	RAB (2011 $m)	Maximum demand (MW) 2010-11
ACT	ActewAGL	50/50	168,937	4,922	635	701
NSW	AusGrid	Government	1,619,988	49,781	8,965	5,812
NSW	Endeavour	Government	877,340	34,172	3,925	4,069
NSW	Essential Energy	Government	1,301,626	190,531	4,595	2,292
NT	Power and Water Corporation	Government	85,000	7,959	2,200	353
QLD	Energex	Government	1,316,295	53,928	8,120	4,875
QLD	Ergon	Government	689,277	160,998	7,380	2,429
SA	SA Power Networks	Private	825,218	87,226	2,860	1,798
TAS	Aurora	Government	275,536	25,844	1,410	1,760
VIC	Citipower	Private	311,590	7,406	1,315	1,453
VIC	Jemena	Private	314,734	6,043	770	1,008
VIC	SPAusNet	Private	637,810	48,841	2,120	1,798
VIC	Powercor	Private	723,094	84,791	2,260	2,351
VIC	United Energy	Private	641,130	12,875	1,410	1,962
WA	Western Power	Government	1,018,275	90,014	6,991	4,068
WA	Horizon Power	Government	109,000	7,299	1,200	-

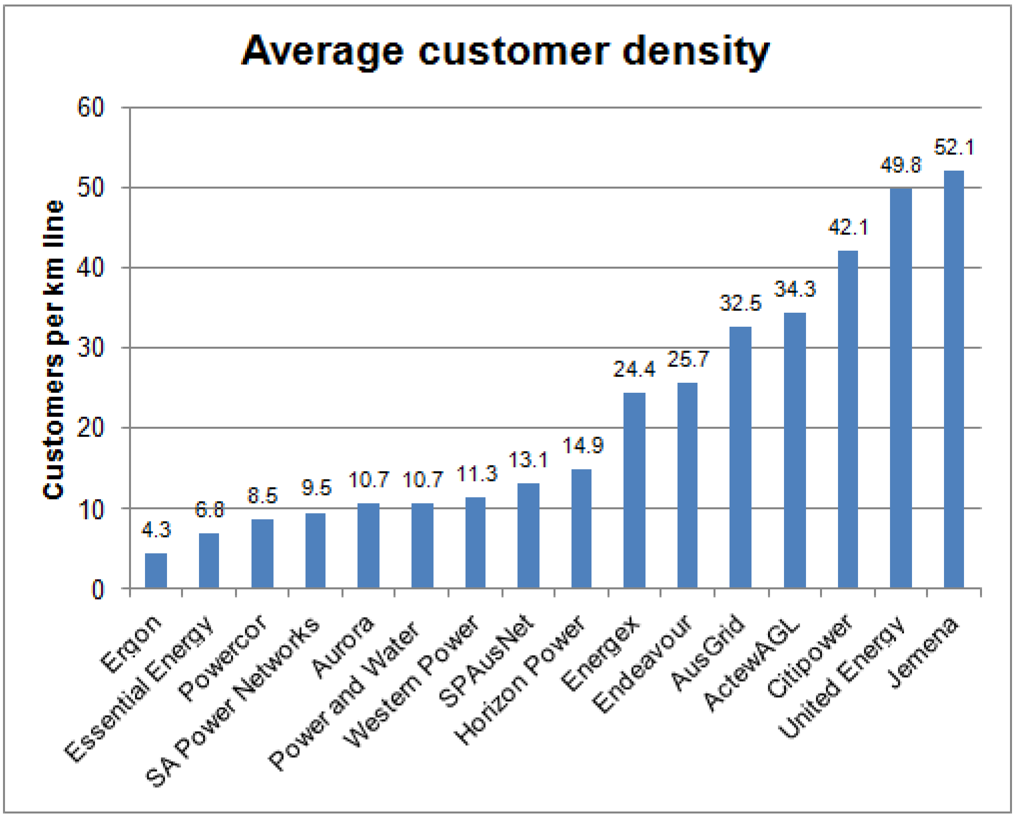
Notes:

1. All NEM data from Australian Energy Regulator. State of the energy market 2012, http://www.aer.gov.au/node/18959

2. RAB = Regulated Asset Base, as defined at the beginning of the regulatory period as: New RAB = Previous RAB – depreciation + capital expenditure from previous regulatory period.

3. WA and NT data from Annual Reports of respective utilities. Power and Water asset base includes water, sewage and electricity infrastructure. NT demand data from Utilities Commission Power System Review 2010-11, aggregate of Darwin-Katherine, Alice Springs and Tennant Creek systems (not necessarily coincident).

As evidenced by the map in Figure 2, the service areas of the utilities vary dramatically. This can also be represented by comparing the average customer density of these companies. This is the number of customers divided by the total kilometres of distribution lines. Using this metric, there is more than an order of magnitude variation between the highest and lowest average customer density.



Data source: Australian Energy Regulator. State of the energy market 2012, http://www.aer.gov.au/node/18959

Figure 2 DNSP average customer density

3 Installed capacity of PV in Australia

3.1 Small-scale PV

AEMO publishes information about the current installed capacity of PV, and projections for installed capacity and energy output (AEMO, 2012). In 2011 it was found that the number of systems recorded by DSNPs was less than the number indicated by the Clean Energy Regulator (CER). This was attributed to missing data, and variations in data collection methodology (e.g. specifying inverter capacity instead of panel capacity).

The CER dataset is the most complete source of publically available data on PV installations. The dataset covers systems that are eligible for the SRES, which are currently those of less than 100kW. There can be up to a year of lag between PV systems being installed and appearing on this list. This data is used in Table 2 below.

Table 2 Small-scale PV generation (less than 100 kW) in Australia in June 2013

State	Total installations (June 2013)	Rated capacity in MW	Customers	% of customers with PV
ACT	12,326	31	168,937	7.3%
NSW	234,118	560	3,798,954	6.2%
NT	2,222	8	85,000	2.6%
QLD	322,497	864	2,005,572	16.1%
SA	143,863	357	825,218	17.4%
TAS	15,128	32	275,536	5.5%
VIC	184,880	419	2,628,358	7.0%
WA	139,122	309	1,127,275	12.3%
TOTAL	**1,054,156**	**2,579**	**10,914,850**	-

Data source:
1. Total PV installation and system size data from Clean Energy Regulator, current as of June 2013
2. Number of customers from Australian Energy Regulator. State of the energy market 2012, http://www.aer.gov.au/node/18959
3. The indicative MW of PV value is the value for that state or territory scaled for the number of customers of each utility

The percentage of customers that have a PV system is highest in Queensland and South Australia.

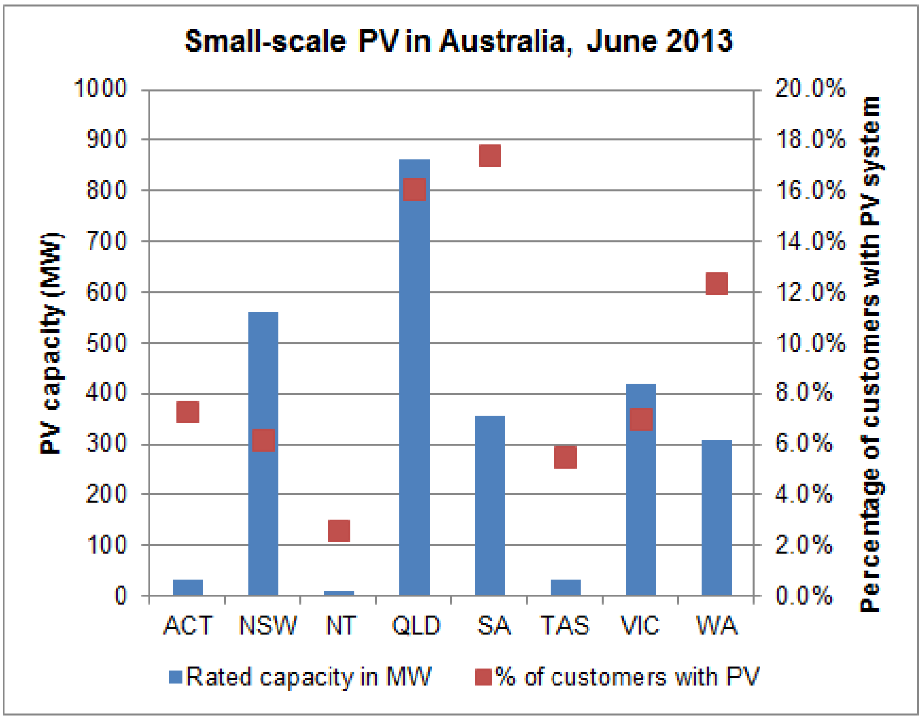


Figure 3 Percentage of PV customers for each Australian state and territory

Table 3 compares the installed capacity of household PV to the average summer and winter demand for each NEM region and the SWIS. The maximum PV percentages are indicative estimates of the maximum PV contribution to demand based on current demand and PV data. It is assumed that, collectively, output of the PV systems will be 80% of their rated capacity in summer and 60% in winter.

Table 3 Indicative maximum PV contribution for NEM regions and SWIS

State	Average Summer demand - 12pm (MW)	Average Winter demand - 12pm (MW)	Rated PV capacity (MW)	Max PV % Summer	Max PV % Winter
NSW	9,413	**9,803**	590	5.0%	3.6%
QLD	**7,003**	5,991	864	9.9%	8.7%
SA	**1,691**	1,655	357	16.9%	12.9%
TAS	1,095	**1,273**	32	2.3%	1.5%
VIC	6,617	**6,704**	419	5.1%	3.8%
WA	**2,447**	2,171	309	10.1%	8.5%

Notes:
1. Demand data from esaa, Electricity Gas Australia 2013. Bold indicates winter or summer peaking region.
2. Total PV capacity installed from Clean Energy Regulator, current as of June 2013.
3. Maximum PV percentages assume peak PV performance of 80% in summer, 60% in winter, as percentage of rated PV capacity. Based on data from Pvoutput.org.

The following DNSPs have indicated the amount of PV that is connected to their network (Ausgrid, 2012a; Endeavour Energy, 2011; Energex, 2012b; Ergon Energy, 2012; Western Power, 2012a):

Table 4 PV installed capacity by DNSP

Utility	PV installed (MW)	Date
Ausgrid	124	June 2012
Energex	569	Dec 2012
Endeavour	105	Sept 2011
Ergon	188	Sept 2012
Western Power	206 (Approx.)	Dec 2011

Owing to the rapid growth in the industry, it is highly likely that even very recent figures are already out of date. The rate of new installations has fluctuating dramatically in response to changes in the incentives offered by the state governments, most of which have now been dramatically reduced. Figure 4 is an example from Western Power (Western Power, 2012a) :

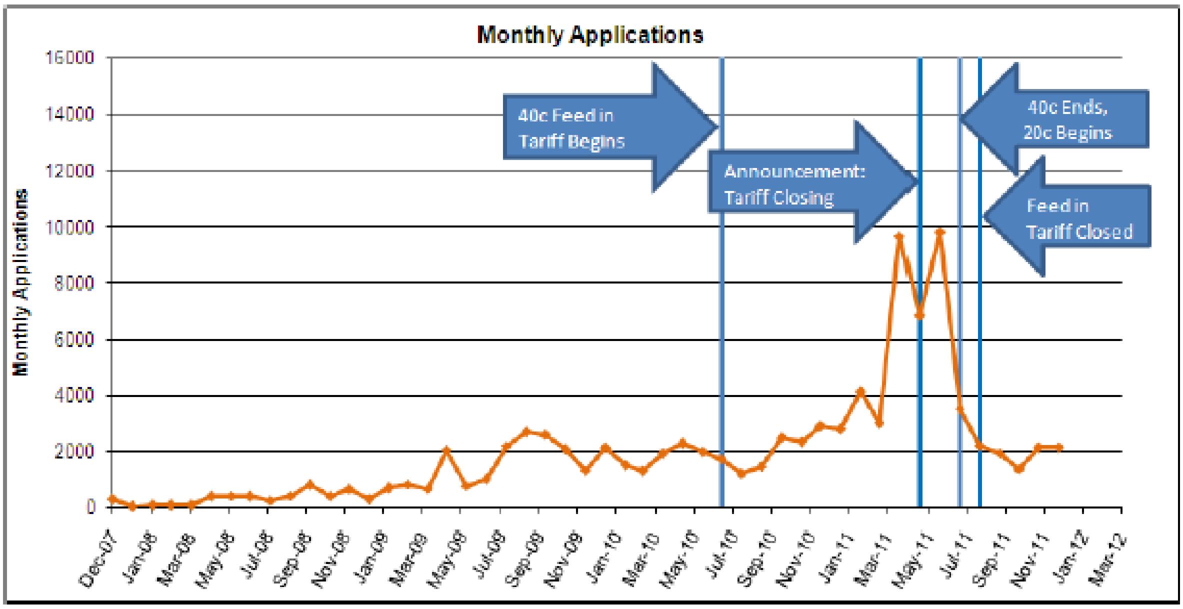


Figure 4 Monthly applications for PV connections observed by Wester Power

The Victorian Department of Primary Industries (DPI) reports on the amount of PV capacity that has been installed under the Premium feed-in tariff (NSW Government, 2012). This accounts for 175 MW of the total 419 MW that is believed to be installed in the state as of March 2013. Based on the amount of PV that was installed under this scheme, an estimate can be made of the capacity of PV that is installed in each distribution area as of March 2013 (see Table 5).

Table 5 Number of Victorian PV customers and installed capacity (DPI, 2013)

DNSP	Number of Premium FiT customers	Premium FiT installed capacity (MW)	Percentage of capacity	Indicative PV installed in June 2013 (MW)
SP Ausnet	29,771	60	34.3%	144
Jemena	8,029	16	8.9%	37
Powercor	29,436	51	34.7%	145
Citipower	3,533	6	3.5%	15
United Energy	17,479	33	18.7%	78
TOTAL	**88,248**	**175**		

It is notable that approximately 70 % of PV capacity in Victoria is connected in the SP Ausnet and Powercor distribution areas.

3.2 Large-scale PV

Table 6 uses information from the CER list of LRET accredited power stations and the SunWiz list of Large PV systems (Sunwiz, 2013). A DNSP has been assigned based on the physical location of each system.

Table 6 Large-scale PV capacity per DNSP

Network company	Large-scale PV capacity (MW)
Western Power	10.28
Power and Water	3.62
Energex	1.43
Power Networks SA	1.22
Horizon Power	0.85
Powercor	0.71
Ausgrid	0.51
Ergon	0.48
Essential Energy	0.27
Citipower	0.21
Aurora	0.09
ActewAGL	0.00
Jemena	0.00
SP Ausnet	0.00
Endeavour	0.00
In doubt	0.09
Total	**19.79**

Data source:
1. PV systems are those that appear on the accredited power stations for the LRET. Clean Energy Regultor, accessed January 2013
https://www.rec-registry.gov.au/searchAccreditedPowerStations.shtml
2. System size from SunWiz Large system list

These figures are much smaller than the amount of small-scale PV. Also the impact of these generators of the network is expected to be less owing to the additional planning and formal network connection process that would occur for a system of this size.

4 Australian standards

The relevant standards that are considered here are AS4777 for *Grid connection of energy systems via inverters*, the AS61000.3.100 standard for *Steady-state voltage limits in public electricity systems*, and AS3000, the Wiring Rules. AS4777 is being revised, with a draft released for public comment on 28 June 2013.

4.1 Current AS4777 – 2005

The existing AS4777 standard is divided into three parts; parts two and three concerning inverter requirements and grid protection requirements respectively are of most relevance for this review. These standards apply to inverters with a rating of up to 10kVA per phase (although they can be used as guidance for larger systems). The key requirements from the 2005 version of AS4777 are summarised in the following sections.

4.1.1 Inverter requirements

- AC voltage and frequency ratings to be compatible with AS 60038 (now replaced by AS 61000.3.100). This is a nominal voltage of 230 V at the point of supply in single phase line-to-neutral and 400 V in three phase line-to-line with a tolerance of +10% -6% and a frequency of 50 Hz.
- Power factor to be in the range from 0.8 leading to 0.95 lagging for all output from 20% to 100% of rated output. However, the electricity distributor can allow power factor outside this range for the purpose of providing voltage support.
- Total harmonic distortion (THD) (to the 50th harmonic) shall be less than 5%.
- The inverter shall conform to the voltage fluctuation and flicker limits as per AS/NZS 61000.3.3 for equipment rated less than or equal to 16 A per phase and AS/NZS 61000.3.5 for equipment rated greater than 16 A per phase.
- The inverter shall withstand a standard lightning impulse of 0.5 J, 5 kV with a 1.2/50 waveform. Compliance shall be determined by type testing in accordance with the impulse voltage withstand test of IEC 60255-5.
- The DC output current of the inverter at the AC terminals shall not exceed 0.5% of its rated output current or 5 mA, whichever is the greater.
- Any electronic data logging or communications equipment incorporated in the inverter should comply with the appropriate requirements of AS/NZS 60950.1.

4.1.2 Grid protection requirements

- The grid protection device shall operate if supply from the grid is disrupted, when grid voltage or frequency goes outside preset parameters, or to prevent islanding.
- Under/over voltage and frequency requirements are passive anti-islanding protection. The inverter set-points should be in the range of fmin = 45-50 Hz, fmax = 50-55 Hz, Vmin = 200-230 V, and Vmax = 230-270 V for a single phase system.
- The grid protection device shall incorporate at least one method of active anti-islanding protection. This is required to prevent islanding occurring in a situation where multiple inverters provide a frequency and voltage reference for one another, causing the passive anti-islanding protection to fail.

- Reconnection is permitted when voltage and frequency are in the acceptable range for at least 1 minute and the inverter energy system and the electricity distribution network are synchronized and in-phase with each other.

4.2 New AS4777

For the new version of AS4777, parts two and three of the old standard have been combined.

The key changes that have been made between the new and the old standard are:

- The standard now applies for a system size of up to 54 kVA[1] (75 A), with a limit of 5 kVA for a single phase unit, (whereas previously the standard applied to 3 phase systems up to 30 kVA, or 10 kVA per phase).
- Systems > 5 kVA to have three phase connections
- The voltage drop between the inverter and the main switch board is to be less than 1%, and the voltage drop between the main switch board and the distributor point of supply is to be less than 1%
- Inclusion of balance requirement in multiple phase systems. In a three phase system the imbalance between the phases must be no more than 20A or 2% of voltage. If these limits are exceeded, the inverter must disconnect.
- Revised inverter set points and limits to match electricity distributor requirements
- Inclusion of demand response modes
- New parameters for power factor and limits for sustained operation

4.2.1 Inverter set points

The following voltage and frequency set points are for passive anti-islanding protection. Table 7 they are compared with the range that was used in the 2005 standard:

Table 7 Inverter set-point requirements AS4777

Set-point	Old AS 4777 (range)	Proposed AS4777 inverter integrated protection	Proposed AS4777: in addition to inverter integrated protection for systems >30 kVA
Vmin	200 – 230 V	180 V	180 V
Vmax	230 – 270 V	265 V	260 V
fmin	45 – 50 Hz	47 Hz	47.5 Hz
fmax	50 – 55 Hz	52 Hz	52 Hz

[1] 54kVA is the apparent power (S) supplied to a three phase inverter with voltage 415V and current 75A. S = $\sqrt{3}$ x IV = 53.91 kVA

There is the potential that the disconnection time will be shorter than the original 2 seconds. Comment is being sought.

It is also noted that additional protection and control approaches may be required by the distributor in isolated electricity distribution networks.

4.2.2 Voltage drop

The voltage drop / rise between the inverter and the main switch board is to be less than 1%, and the voltage drop / rise between the main switch board and the distributor point of supply is to be less than 1%. This is depicted in Figure 5 (Taylor, 2013).

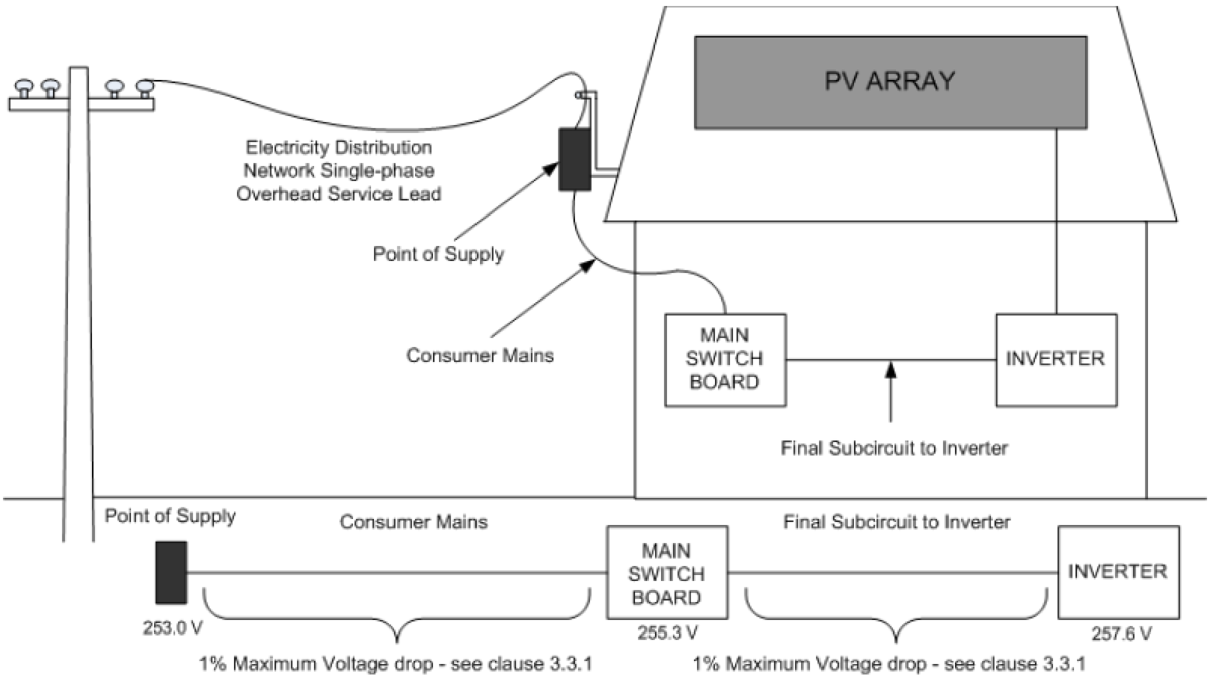


Figure 5 Voltage drop provisions specified in draft AS4777.1 of 2013 (Taylor, 2013)

It is noted in the draft that the voltage drop allowed under AS/NZS 3000 between the inverter and the customer point of supply is currently 5%, but under such conditions, inverter tripping on under/over voltage may be excessive for some installations. Within the 5% window, the voltage at the inverter can move outside the AS4777 voltage set points, while the voltage at the point of supply remains within distributor's regulatory limits.

4.2.3 Limits for sustained operation

The inverter must disconnect within 3 seconds when the average voltage for a 10 minute period exceeds the maximum nominal operating voltage. This voltage is to be in the range of 244 to 258 V. The default set-point is 255 V for Australia, and 246 V for New Zealand.

The inverter shall operate normally between 47 Hz and 50.2 Hz. If grid frequency exceeds 50.2 Hz, the inverter current shall reduce until 51.5Hz is reached at which point inverter current must stop. The current can be increased when grid frequency has decreased to 50.05 or less.

4.2.4 Power factor

The displacement power factor of the inverter should be set to operate at unity power factor, but should be adjustable and must be in the range of:

- 0.95 leading to 0.95 lagging for inverters with rated nominal output currents up to 20 A per phase or;
- 0.90 leading to 0.90 lagging for inverters with rated nominal currents greater than 20 A per phase.

This is applicable for current output from 20% to 100% of rated nominal output current. Wider power factor operation may be required via demand response modes as described below.

4.2.5 Inverter power quality response modes

Additionally, the inverter can play a role in maintaining the power quality at the point of connection through:

- Volt-Watt Response
- Volt-VAr Response
- Fixed power factor or reactive power
- Power rate limit

In terms of power rate limit, the inverter should have the capability to limit the increase in power export to 10% of nominal rated capacity per minute. If the inverter has storage capabilities, it should also be able to limit the decrease in power export by 10% per minute.

4.2.6 Demand response

The inverter shall support the demand response modes DRM0 and DRM5 to be controllable by the distributor, as described in Table 8. The other demand response modes should be supported.

Table 8 Demand response modes for inverter performance

Mode	Requirement
DRM0	Operate the disconnection device
DRM1	Do not consume energy from the grid
DRM2	Do not consume at more than 50% of rated power
DRM3	Do not consume at more than 75% of rated power AND Export reactive power if capable

DRM4	Increase power consumption (subject to constraints from other active DRMs)
DRM5	Do not export energy to the grid
DRM6	Do not export at more than 50% of rated power
DRM7	Do not export at more than 75% of rated power AND Consume reactive power if capable
DRM8	Increase power export (subject to constraints from other active DRMs)

There is in additional provision in the reconnection requirements that reconnection cannot occur while the DRM0 mode is still active.

A new standard AS 4755.3.5 will provide more details about demand response requirements.

4.3 AS61000.3.100 – Steady-state voltages

This standard defines the steady-state voltage limits in public electricity systems. It is a method of measuring the compliance of the supplied voltage at the point of supply. The new standard sets a nominal voltage of 230 V, whereas previously this was 240 V. It defines both an allowable operating range, and a preferred operating range. The preferred operating range is +6% to –2%, however the allowable voltage variation at the point of supply of +10% and –6%. The preferred operating range represents the 50 percentile value of voltage while the upper and lower limits are the 99 and 1 percentile values respectively. This is represented both numerically and graphically below.

In Table 9, the voltage specifications from AS61000.3.100 are compared to those from AS60038 – Standard Voltages. The latter are standards used by equipment manufacturers to ensure that the products they produce are compatible with the local power system.

Table 9 Voltage requirements under AS 60038 and AS 61000.3.100

Voltage	AS 60038	AS 61000.3.100
Max allowable		253 V (99%)
Max preferred	253 V	244 V (50%)
Nominal	230 V	230 V
Min preferred	216.2 V	225 V (50%)
Min allowable		216 V (1%)

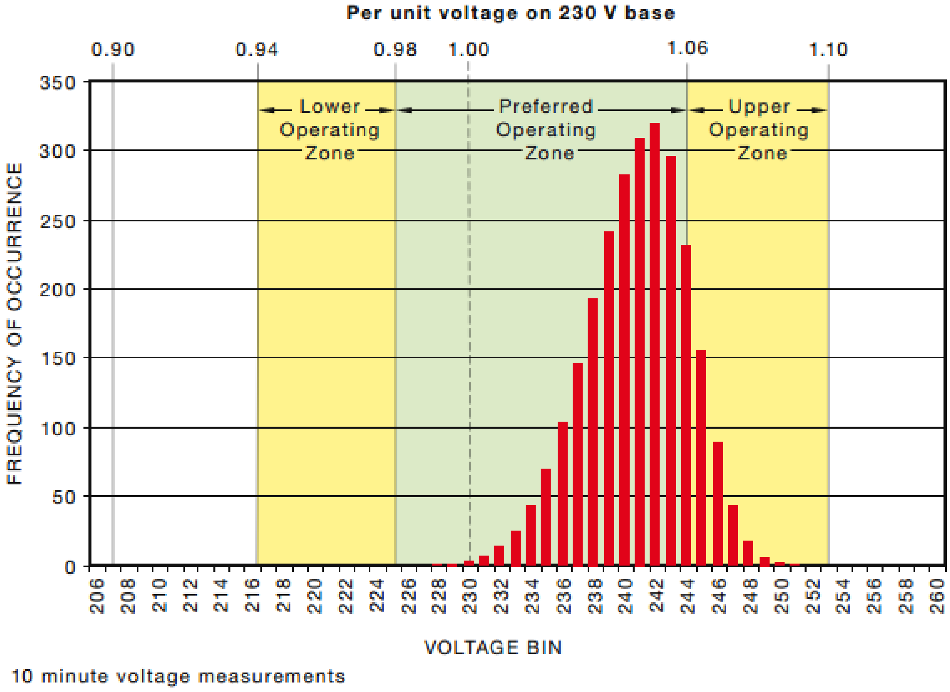


Figure 6 Voltage operating zone specified by AS 61000.3.100

In Figure 6, the red bars are a voltage distribution for a site that complies with the preferred and allowable voltage conditions (Table 9). It is notable that there is not much flexibility for accommodating voltage rise from solar inverters because high voltage levels already exist. It is plausible that this could also be the case for DNSPs.

4.4 AS3000 – Wiring rules

The AS4777 standard is a normative reference of AS3000. Of most relevance in AS3000 is section 3.6.2 that specifies that a voltage drop of no more than 5% is allowed between the point of supply and any point in the electrical installation (e.g. an inverter).

AS 3000 does not specify a limit on voltage rise, but there is the potential for this to be included in the future.

4.5 AS4577 – Demand response capabilities

AS 4577 – 2007 provides a framework for the control of electrical devices that can alter their electricity demand in response to an instruction from a remote agent (e.g. the electricity supply utility). Part 3 provides operational instructions for specific devices. Sub-sections 3.1 and 3.2 respectively cover air conditioners and swimming pool pump units and are currently available. As of January 2013, operational instructions are pending for the following product categories:

- Electric and electric-boosted hot water systems
- Charge/discharge controllers for electric vehicles and other energy storage devices
- Inverters and controllers for PV and other small-scale generators

5 State-based standards for power quality

5.1 Voltage

The standards for voltage that Australian distribution network service providers (DNSPs) must comply with are determined individually by each state and territory. At the current time there is a group of states that have adopted the new nominal voltage of 230 V +10% / -6% (New South Wales, South Australia, Tasmania and Victoria) and a group that are yet to change over and maintain a nominal voltage of 240 V +/-6% (ACT, NT, Queensland and Western Australia). The Northern Territory has a nominal voltage of 230 V +10% / -2% and is moving towards a standard voltage range of +/- 6% (Power and Water Corporation, 2008).

In Victoria, and for Ausgrid in New South Wales, there is an allowance for voltages in the range of 207 to 262 V (i.e. 230 V +14% / -10%) for durations of less than 1 minute. This is represented below (Ausgrid, 2011a).

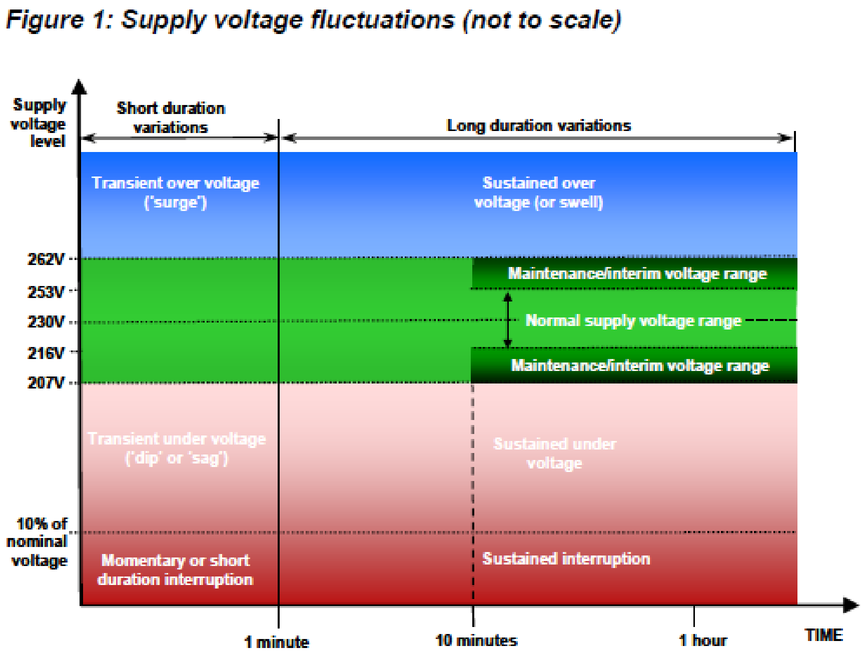


Figure 7 Allowable supply voltage fluctuations on the Ausgrid network

In New South Wales and the SWIS there is a 1% limit on voltage rise for embedded generators connected by inverters (NSW Government, 2012; Western Power, 2011). For the SWIS this is defined as a rise "across the service leads"; the New South Wales Service and Installation Rules specify that, "the maximum permissible voltage rise on the underground or overhead service main must not exceed 1%". The service main is the line between the point of supply and point of common coupling.

5.2 Frequency

In the NEM regions, the network frequency is maintained by the Australian Energy Market Operator (AEMO), and the threshold is specified by the Australian Energy Market Commission (AEMC). There is a standard for Tasmania, and another standard for the rest of the NEM regions (AEMC, 2008; AEMC Reliability Panel, 2009), as shown in Table 10. The non-NEM regions of the Northern Territory and Western Australia have frequency standards that are defined by the respective utilities in those jurisdictions (Power and Water Corporation, 2003; Western Power, 2012b).

Table 10 Mainland frequency operating standards in the NEM

Condition	Containment	Stabilisation	Recovery
Accumulated time error	5 seconds		
no *contingency event* or *load event*	49.75 to 50.25 Hz, 49.85 to 50.15 Hz 99% of the time	49.85 to 50.15 Hz within 5 minutes	
generation event or *load event*	49.5 to 50.5 Hz	49.85 to 50.15 Hz within 5 minutes	
network event	49 to 51 Hz	49.5 to 50.5 Hz within 1 minute	49.85 to 50.15 Hz within 5 minutes
separation event	49 to 51 Hz	49.5 to 50.5 Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes
multiple contingency event	47 to 52 Hz	49.5 to 50.5 Hz within 2 minutes	49.85 to 50.15 Hz within 10 minutes

5.3 Additional Requirements

Some state standards also have power factor and voltage impulse limits (Victorian Essential Services Commission, 2012; Western Power, 2012b). These provisions, as well as the specified ranges for system voltage and frequency, are shown in Table 11 below.

Table 11 Voltage and frequency requirements for Australian states and territories

Provision	ACT	New South Wales	Northern Territory	Queensland	South Australia	Tasmania	Victoria	Western Australia
Voltage_High	254	253	253	254	253	253	253	254
Voltage_Nominal	240	230	230	240	230	230	230	240
Voltage_Low	226	216	226	226	216	216	216	226
Frequency_High	50.25	50.25	52	50.25	50.25	50.5	50.25	51.25
Frequency_Nominal	50	50	50	50	50	50	50	50
Frequency_Low	49.75	49.75	47	49.75	49.75	49.5	49.75	48.75
Additional provisions		V range for 98% percentile, otherwise 207-262V "maintenance/interim voltage range"; Max 1% voltage rise on service main.	Nominal supply voltage 230V +10%, -2%. Moving towards +/-6%. Power factor not less than 0.85.			Voltage of +/- 10% allowed for less than 1min. Power factor of 0.75 lagging to 0.8 leading for up to 100kVA at <6.6kV supply.	Voltage of +14% and -10% allowed for less than 1min, meaning max 262V. Power factor of 0.75 lagging to 0.8 leading for up to 100kVA at <6.6kV supply. Impulse voltage 6 kV peak	Power factor of 0.8 lagging to 0.8 leading for loads of < 1MVA; Voltage rise across service leads less than 1% of rated volts.
Source	Independent Competition and Regulatory Commission	AusGrid; NSW Gov	Power and Water Corporation	Queensland Electricity Regulator	SA Power Networks	Office of the Tasmanian Economic Regulator	Victorian Essential Services Commission	Western Power/ Horizon Power
Source document	Electricity Distribution (Supply Standards) Code	Electricity Network Operation Standards; S&I Rules	Service Rules; Network Connection Tech Code	Electricity Regulation 2006	Service and Installation Rules	Tasmanian Electricity Code	Electricity Distribution Code	WA Distribution Connections Manual 2012; Technical Rules
Date	Dec 2000	Oct 2011; Aug 2012	Aug 2008; April 2003	Nov 2012	Sep 2012	Jan 2013	May 2012	May 2012; Dec 2011

* Red indicates AEMC standard for "no contingency or load event"

6 Utility guidelines for PV connection

Most DNSPs publish guidelines for customers (and in some cases installers) who intend to connect solar PV systems to their network. The majority of the DNSPs have published a dedicated document for small PV connections. A summary of these policies is given in Table 12.

The content of these policies varies significantly. One point of difference is the maximum system size limit that is allowed. Power and Water, Ergon, SP AusNet and Western Power specify limits in the vicinity of 3.5 to 5kW per phase for residential connections. Often it is stated that for systems larger than this is a detailed “technical study” is required. ActewAGL provides a table that outlines the scope of their network technical study; it involves checking the loading level on the 11kV feeder, LV feeder, and distribution transformer; the fault level and protection settings; and the nature of other distributed energy systems to assess risk of unintentional islanding (ActewAGL, 2011).

Western Power states that loading limits apply on various levels of network infrastructure, including a 30% limit on the LV feeder, and 20% on the zone substation transformer (Western Power, 2012b). SA Power Networks states that such limits may be necessary in the future to minimise the impact of “harmonic saturation” (SA Power Networks, 2012).

Five of the utilities specify voltage and frequency set-points for inverters that connect to their networks. These set-points are *mostly* compliant with the current and proposed AS4777 standards. In some instances, PV systems over a specified size must install remote monitoring capabilities (e.g. ActewAGL and SA Power Networks). This is to allow the DNSPs to access real-time data for larger PV installations that could impact on the operation of the network.

The Horizon Power guidelines contain provisions for PV output smoothing and “feed-in management” that apply when the “hosting limit” of a particular location has been reached (Horizon Power, 2012b). The utility also publishes a document (and has a search function on their website) that indicates the current available hosting capacity in each location.

Table 12 Summary of PV system connection guidelines

State	Company	Dedicated public policy for PV (Y / N)	System size limit before tech assessment	Other provisions	Metering offered	Voltage and frequency set-points	Note	Source document	Publication date
ACT	ActewAGL	Y	10kW single phase, 200kW three phase	Max 10% variation between phases (new AS4777 says max 20A). Systems of 61 to 200kW considered for SCADA integration with network operator.	Net or gross		Network study procedure is given	Guidelines for photovoltaic installations up to 200kW connected via inverters to the ActewAGL network	Nov-11
NSW	AusGrid	N, but covered in general policy	10kW per phase		Net			Customer Connection Information, section 4.5 for PV	Jul-11
NSW	Endeavour	N	30 kW	Systems above 5 kW must be installed on multiple phases as per the NSW service and installation rules		Supply frequency 49.5 - 50.5 Hz, voltage within +14% to -6%, but mostly +10% to -2%	Standard written but not yet ready for public disclosure as of January 2013	N / A, personal communication	
NSW	Essential Energy	Y	10kW	Cannot mix solar, wind, hydro.	Net or gross		Guidelines mainly for DC isolation circuit breakers	Solar PV Connection requirements	Apr-11
NT	Power and Water Corporation	Y	4.5kW residential, 30kVA for 3 phase commercial		Gross metering, $521 for single phase, $671 for three phase	fmin = 46, fmax = 54, Vmin = 210, Vmax = 270. Compliant with current, but non-compliant with proposed AS 4777	Specific surge protection for lightening, and wind loading provisions for cyclones	Technical requirements for grid connection of PV	Nov-10
QLD	Energex	Y	10kW	More than 3kW per phase may have to pay for metering (10kW for three phase)	Net or gross	fmin = 48, fmax = 52, Vmin = n/a, Vmax = 255. Compliant with current and proposed AS 4777	Vmax set-point is notably less than other DNSPs	Connecting Your Inverter Energy System to the Energex Network	Jul-12
QLD	Ergon	Y, website	5kW, 2kW for SWER, all connections for remote locations			Vmax = 255 V	Technical assessment does not seem to consider onsite load	Ergon Energy website	Jan-13
TAS	Aurora	Y	10kW, or 30kW three phase		Net		Flow chart of connection process for consumer	Guideline for the Connection of Micro Embedded Generators to the Aurora Distribution Network (AS4777 Compliant)	Jul-12

SA	SA Power Networks	Y	10kW, 5kW for SWER network	Remote monitoring requirements for more than 10kW	Import/ export	"Capable of operation within" 230V +10% and -6%	Envisage kVA limits per transformer to minimise impact of "harmonic saturation". Potential issues noted include network load balance, network thermal overload, and harmonic stauration	Small Embedded Generation Network Connection	Sep-12
VIC	CitiPower	Y	10kW per phase, unless rural location		Smart meter	fmin = 48.5, fmax = 51.5, Vmin = 195, Vmax = 265 as per AS 4777.3. Compliant but frequency range more narrow than proposed AS4777. Reconnection when 200 to 260V and 49 to 51 Hz for 1min		Grid connected renewable energy system technical guidelines	Oct-09
VIC	Jemena	Y	10kW per phase					Solar generator connection obligations	May-10
VIC	SPAusNet	Y	3.5kW per phase SWER, 4.6kW single phase, 5kW three phase	Pre-approval fees of $200 for > 4.6kW and $2000 for 30 to 200kW			Assessments use panels ratings not inverter rating	Inverter Energy systems minimum requirements	Dec-12
VIC	Powercor	Y	10kW per site	See CitiPower entry					
VIC	United Energy	Y	10kVA per phase						
WA	Western Power	Y	5kVA single phase, 30kVA three phase	Generally systems more than 3kW in metropolitan and 1.5kW in regional areas subject to "analysis or investigation". No more than 2.5kVA phase imbalance for multi-phase systems. EG limits of 30% of transformer capacity or 30% of LV feeder capacity measured in kVA. Max connection to zone substation transformer	Import/ export	Network voltage limits 226 to 254 V, frequency set-points appear to be 47.5 and 52Hz		WA Distribution Connections Manual 2012	May-12
WA	Horizon Power	Y	10kW per phase	Generation management (output smothing and feed-in management) depending on local hosting capacity. System cannot import power, export only. Phase imbalance for multi-phase must be less than 2.5kVA	Bi-directional	fmin = 46.5, fmax = 53, Vmin = 190, Vmax = 265 as per AS 4777.3. Frequency range greater than proposed AS4777	Publish document of available hosting capacity by individual township	Technical requirements for renewable energy systems	Jul-12

7 Utility submissions and presentations on PV impacts

In order to better understand the efforts of DNSPs to manage growing PV penetrations, relevant information has been collected from a range of submissions and presentations that they have made to government enquiries and at industry conferences over recent years. Most of the submissions reviewed are for the regulatory reviews of the state-based solar feed-in tariffs that were conducted in NSW, Queensland, and Victoria in 2011 and 2012. Owing to the differing scope and contexts for the various reviews, the submissions that the DNSPs have made do not all focus on the same issues. Instead, for the purpose of this literature review some observations are made under the following subheadings:

- The impact of PV on peak demand
- Technical challenges encountered
- Management strategies
- Metering options for PV

Some information included in DNSP presentations is used to supplement these issues raised in the submissions. We report on some of the key findings below.

7.1 Impact on peak demand

In the DNSP sources reviewed it was generally acknowledged that PV can be beneficial to the network if PV output can reduce summer peak demand, and defer capital expenditure. Most DNSPs noted the lack of correlation between peak PV output and peak demand, some on a theoretical basis (Endeavour Energy, 2011), others by using actual observed data (Ausgrid, 2011b). Figure 8 is taken from the Endeavour Energy submission to the NSW Independent Pricing and Regulatory Tribunal (IPART). It compares theoretical solar output with the demand at a major zone substation.

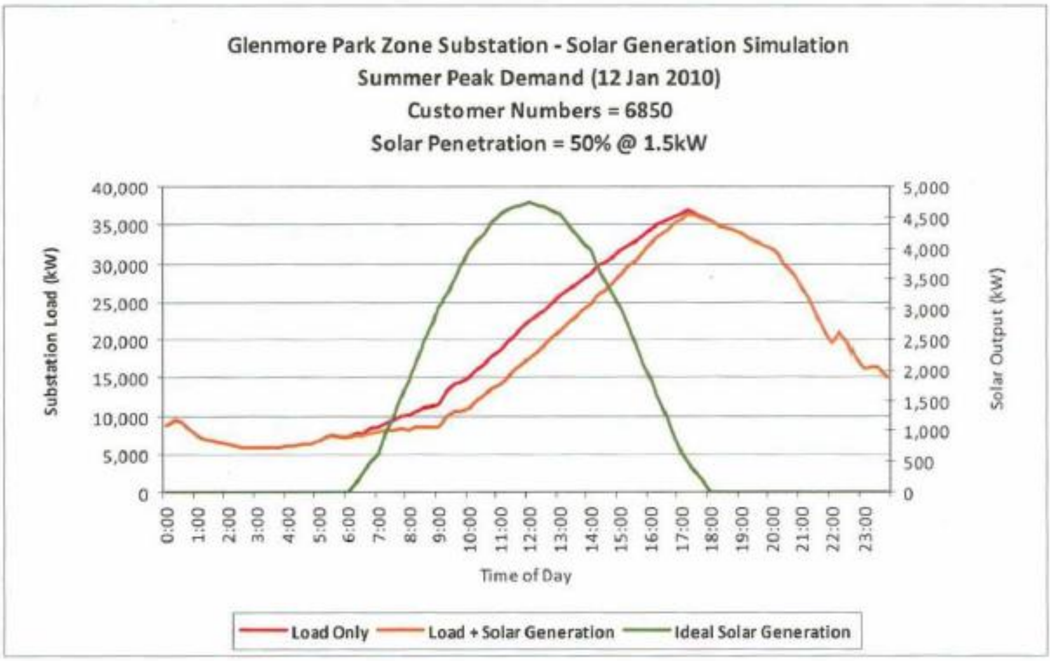


Figure 8 Theoretical solar output compared to substation demand (Endeavour Energy, 2011)

Ausgrid and Western Power have conducted analysis on the peak reduction impact of PV at a whole network business level, and for individual substations, using observed data (Ausgrid, 2011b; Western Power, 2012a). The Ausgrid analysis focuses on the top five peak days in the 2010-11 summer (see Table 13 below). The total rated PV generation capacity of 55.2 MW was found to achieve an average reduction of 0.38%, or 21.8 MW, across the five summer peaks.

Table 13 Estimated solar impact on Ausgrid network summer peaks for summer 2010/11

Summer Peak Day	Date	Day	Time of Peak (EST)	Actual System Peak (MW)	Estimated Solar impact (MW)	% Reduction
1	3/02/2011	Thu	4:00 PM	6,072	18.0	0.30%
2	1/02/2011	Tue	4:00 PM	5,922	22.5	0.38%
3	2/02/2011	Wed	4:00 PM	5,802	21.6	0.37%
4	4/02/2011	Fri	3:30 PM	5,553	23.9	0.43%
5	31/01/2011	Mon	4:00 PM	5,423	22.9	0.42%

It is notable that the PV capacity on the Ausgrid network was 124 MW in June 2012 (Ausgrid, 2012a), which is more than double the 55.2 MW figure that was current at the time of the analysis.

The Western Power analysis does not include data for total PV output, and instead estimates this through a range of methods based on the data that is available. The report states that the peak reduction results from these methods are very similar. The average system impact is projected out to 2017 (Table 14):

Table 14 Projects of solar peak reduction impact on the Western Power network

Year	PV Capacity (MW)	Forecast Peak (MW)	Peak Reduction (MW)	Peak Reduction (%)
2013	243	4,093.09	72.26	1.77%
2014	299	4,208.01	88.52	2.10%
2015	357	4,324.27	105.36	2.44%
2016	414	4,438.31	121.90	2.75%
2017	472	4,584.49	135.33	2.95%

Both the Ausgrid and Western Power also calculate the peak reduction potential for the top substations by PV penetration (and the top 5 11 kV feeders in the case of Ausgrid). The Ausgrid study calculates the solar impact as a percentage of zone annual demand growth (see Table 15 and Table 16). At the time of the analysis there was only one instance (Lisarow 11 kV feeder) where there was enough PV to defer investment by one year (if augmentation would otherwise be required), although it should be noted that assuming uniform growth in PV capacity across the network, a number of the zone substations and three of the five top 11 kV feeders would have solar impact greater than demand growth.

Table 15 Solar impact on summer peak 2011 at top five Ausgrid zone substations

Zone	Zone peak Date and Time	Zone peak MVA	Rated Capacity of Solar Connected at time of summer peak 2010/11 (MW)	Estimated solar impact at time of summer peak 2010/11 (MW)	Estimated % peak reduction	Zone demand rate of growth in MVA/yr	Solar impact as % of zone annual demand growth
Pennant Hills	5/02/2001 17:30	83.75	1.33	0.38	0.5%	1.20	32%
Pennant Hills	3/02/2011 17:30	79.84	1.33	0.33	0.4%	1.20	28%
Pennant Hills	2/02/2011 17:00	79.85	1.33	0.49	0.6%	1.20	41%
Pennant Hills	4/02/2011 17:00	75.64	1.33	0.54	0.7%	1.20	45%
Avoca	5/02/2011 16:00	43.27	0.93	0.50	1.2%	0.58	86%
Avoca	3/02/2011 18:00	40.50	0.93	0.18	0.4%	0.58	31%
Avoca	1/02/2011 18:30	39.71	0.93	0.11	0.3%	0.58	19%
Avoca	2/02/2011 18:30	36.70	0.93	0.11	0.3%	0.58	19%
Nelson Bay	3/02/2011 17:30	44.28	0.97	0.31	0.7%	0.66	47%
Nelson Bay	5/02/2011 18:00	42.64	0.97	0.26	0.6%	0.66	39%
Nelson Bay	2/02/2011 17:30	38.76	0.97	0.35	0.9%	0.66	53%
Nelson Bay	1/02/2011 17:30	37.73	0.97	0.34	0.9%	0.66	52%
Sefton	1/02/2011 17:00	76.06	0.68	0.27	0.4%	1.53	18%
Sefton	2/02/2011 16:30	72.95	0.68	0.33	0.5%	1.53	22%
Sefton	3/02/2011 17:00	72.40	0.68	0.27	0.4%	1.53	18%
Sefton	31/01/2011 16:30	70.39	0.68	0.33	0.5%	1.53	22%
Charmhaven[1]	3/02/2011 16:30	44.24	0.93	0.24	0.5%	1.51	16%
Charmhaven[1]	1/02/2011 17:30	43.73	0.93	0.31	0.7%	1.51	21%
Charmhaven[1]	5/02/2011 17:30	43.50	0.93	0.31	0.7%	1.51	21%
Charmhaven[1]	2/02/2011 18:00	39.77	0.93	0.24	0.6%	1.51	16%

Table 16 Solar impact on summer peak 2011 at top five Ausgrid 11 kV feeders

Zone	11kV Feeder No.	Feeder Peak (MVA)	Peak Date	Time	Rated Capacity of Solar Connected at time of summer peak 2010/11 (MW)	Estimated solar impact at time of summer peak 2010/11 (MW)	% peak reduction	Demand rate of growth in MVA/yr	Solar impact as % of annual demand growth
Homebush[1]	19	4.88	31/01/2011	14:30	0.54	0.15	2.9%	0.22	67%
Flemington[1]	25	4.80	3/02/2011	15:30	0.42	0.07	1.5%	0.08	95%
Lake Munmorah	7	6.84	5/02/2011	19:00	0.29	0.01	0.1%	0.17	6%
Raymond Terrace	2005	6.98	3/02/2011	18:00	0.19	0.03	0.4%	0.13	23%
Lisarow	9	4.14	5/02/2011	18:00	0.28	0.04	0.8%	0.03	122%

The highest instances of solar impact are when the peak occurs around 3:30PM and 4:00PM.

Western Power analysed the top 8 substations by PV penetration. The latest peak load from these substations was 7:45PM and the earliest was 3:15PM. The latter was the Canningvale substation that has a mix of commercial and residential customers. Due to good correlation with the solar resource, the greatest peak load reduction of the top substations was estimated for Canningvale, a reduction of between 1.65 and 1.95% in 2011.

Table 17 Estimated solar impact on Western Power Canningvale substation in 2011

Scenario	Peak Load	Reduction	Peak Load Time
Actual 2011 Peak Profile	75.38		3:15 PM
Profile plus PSC Metered - Summer	76.62	-1.65%	3:15 PM
Profile plus WPN Metered - Summer	76.73	-1.78%	3:15 PM
Profile plus Simulated PV Data - Load on 10 Peak Days	76.69	-1.74%	3:15 PM
Profile plus PV Saturation Trial	76.85	-1.95%	3:15 PM

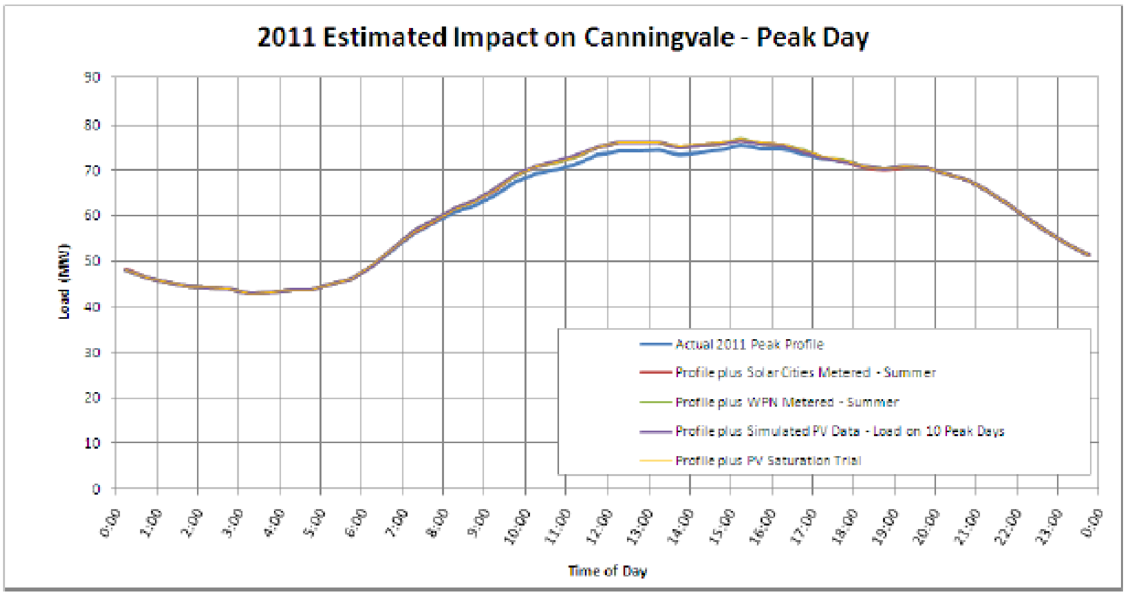


Figure 9 Plot of estimated solar impact on Western Power Canningvale substation in 2011

A potential peak load reduction of up to 2.95% was projected for 2017. In the Western Power report no comment is made of how these potential reductions compare to the peak load growth, and the timing of any anticipated infrastructure augmentation.

7.2 Technical challenges

Inverter tripping due to over-voltage was noted as a common occurrence by Essential Energy and Endeavour in submissions to the IPART solar feed-in tariff review. Essential said that in 2011, 60 to 70% of the power quality issues on the network were related to voltage rise caused by PV systems and inverter tripping (Essential Energy, 2011). In 2010-11, Endeavour visited 95 households in response to inverters tripping. Most were systems larger than 5kW connected by single phase in semi-rural areas (Endeavour Energy, 2011).

Ausgrid also provides an example of over voltage at a 10kW system connected to a single phase (Ausgrid, 2012c). The voltage at the point of supply was regularly above 263V (see Figure 10 below).

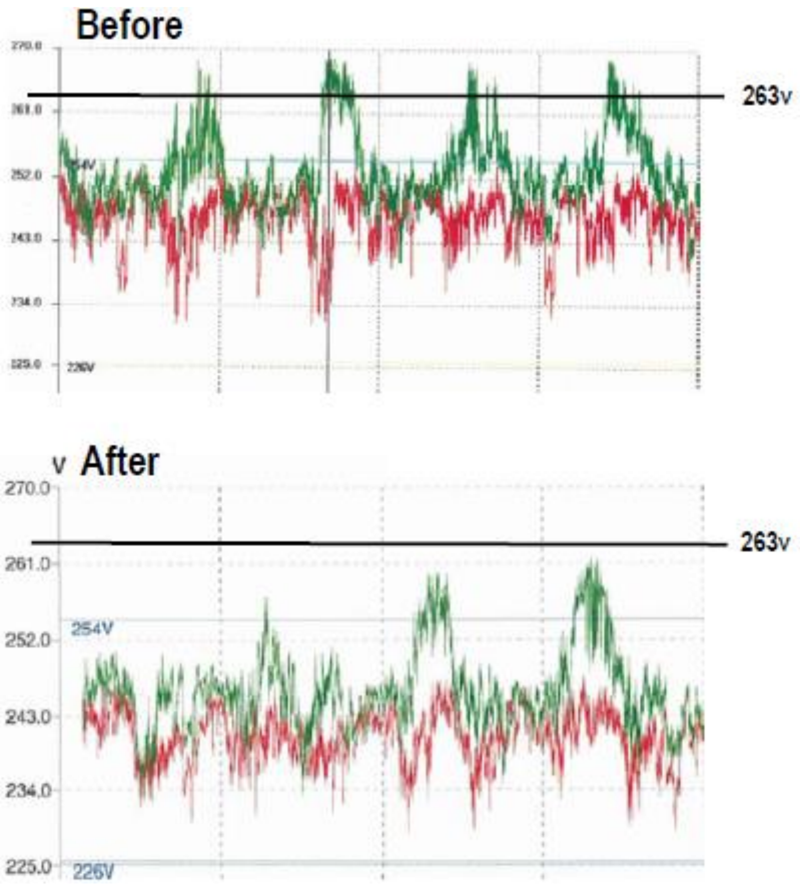


Figure 10 Ausgrid voltage study of 10 kW PV system connected to single phase, before and after line upgrade

Figure 11 is a voltage “heat map” that shows instances of over-voltage that may be due to a cluster of PV installations (Ausgrid, 2012b). This graphic is for the Nelson Bay area of NSW and was produced for the Smart Grid Smart City project.

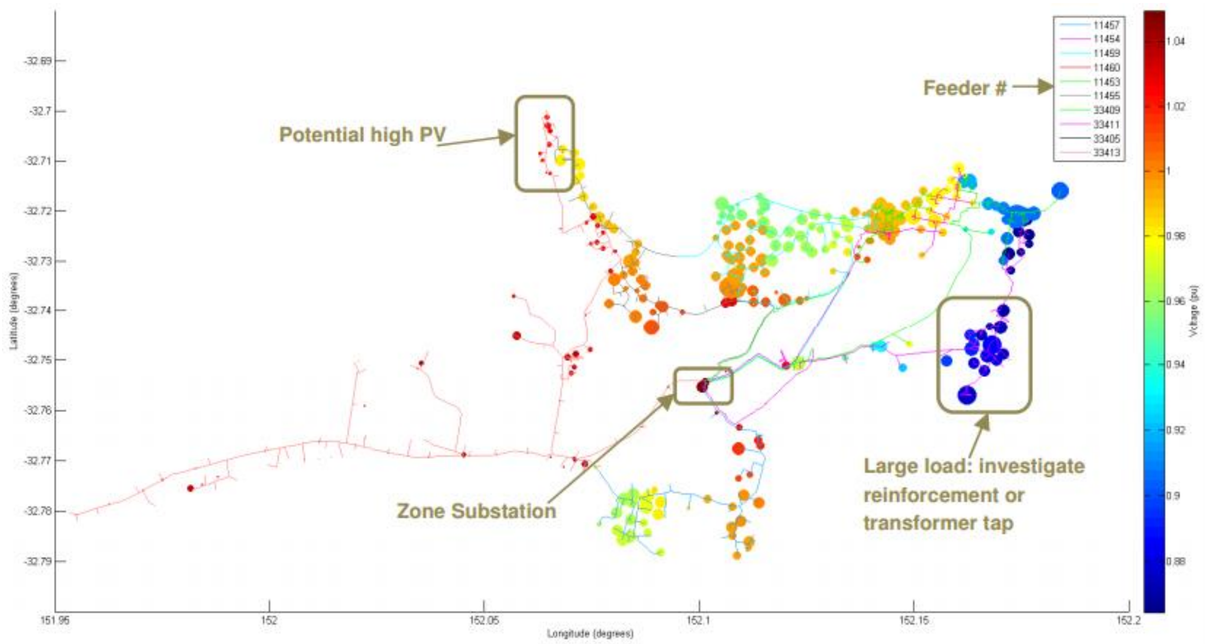


Figure 11 Voltage heat map produced for Smart Grid Smart City (Ausgrid, 2012b)

Ergon Energy, in a submission to the Queensland Competition Authority, notes that the limiting factors for PV hosting capacity in remote parts of their network are the response time of the diesel generators for solar intermittency, and the minimum loading on the generators. Other PV-related issues that are mentioned by Ergon are voltage imbalance, system stability on isolated networks, and the potential for reverse flow into the high voltage network (Ergon Energy, 2012).

7.3 Management strategies

Endeavour Energy lists four ways of increasing the amount of PV that can be installed on the network. These are allowing inverter trip voltages to be higher, tapping down the distribution transformer voltage, augmenting customer service mains to reduce impedance to solar customers, and installing bi-directional voltage regulators (Endeavour Energy, 2011).

Essential Energy suggests the introduction of incentives to tilt panels so that PV output is better correlated with peak demand (Essential Energy, 2011).

A presentation from the Clean Energy Week 2012 documents the strategies that Horizon Power has for PV integration (Horizon Power, 2012a). Hosting limits have already been implemented depending on how much PV is already connected at a particular location. Generation management though output smoothing requirements and (in isolated cases) feed-in management (where Horizon can remotely curtail or disconnect system if necessary) have been introduced in locations where the hosting capacity has been exceeded. A credit for "firm capacity" is noted as a future PV integration strategy. Under this incentive, a PV generator is provided a credit that reflects the ability of the PV system to produce electricity at the time when system peak demand is greatest (see Figure 12).

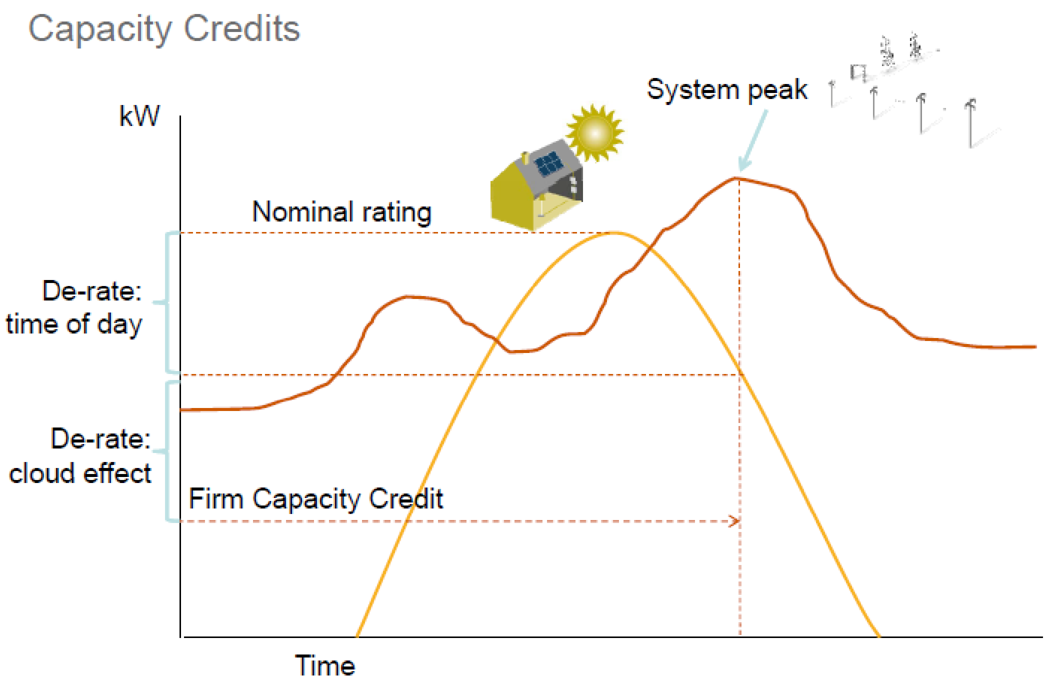


Figure 12 Visual representation of capacity credit incentive for PV (Horizon Power, 2012a)

7.4 Metering

The type of metering for PV systems that is more prevalent in each state and territory is a reflection on the design of the solar feed-in tariff in each jurisdiction. A gross feed-in tariff operates in the ACT, Northern Territory, and for NSW Solar Bonus Scheme participants. All other states and territories, including NSW since the Solar Bonus Scheme has concluded, use net metering as the default arrangement for PV connections (QCA, 2012).

In the various feed-in tariff submissions there are differing opinions regarding how PV should be metered. Some DNSPs (particularly Essential Energy and Endeavour) observe a trend towards net metering, especially now that the buy-back rate for exported energy is less than the retail tariff in NSW. It is noted that more net metering will reduce the amount of energy that is transported through the network, and hence reduce the network revenues that these companies receive. Essential Energy says that gross metering should be mandatory.

Energex has indicated the reduction in Distribution Usage of Service (DUoS) charges collected is as high as 15% on some feeders on sunny days (Energex, 2012a). Despite this, both Energex and Ergon maintain that net metering, where the rate paid for the exported energy is lower than the retail tariff, is preferable over gross metering. The rationale from Ergon is that under net metering customers have a greater incentive to match their household usage with the solar PV output, and that a transition from net to gross metering would be a costly exercise. Similarly, Energex states that net metering should result in lower administration and metering costs. In Victoria, Jemena states that gross metering would be too costly because their IT systems are already configured for single element smart meters (Jemena Energy Networks, 2012).

Citipower/Powercor raises concerns about reduced use of the network by PV customers, which it calls a cross-subsidy, since DNSPs are not able to recover network usage charges from PV customers. This is illustrated in Figure 13. The “indirect subsidy” represents the energy generated from PV and used on site, avoiding the need to use the network (CitiPower and Powercor Australia, 2012).

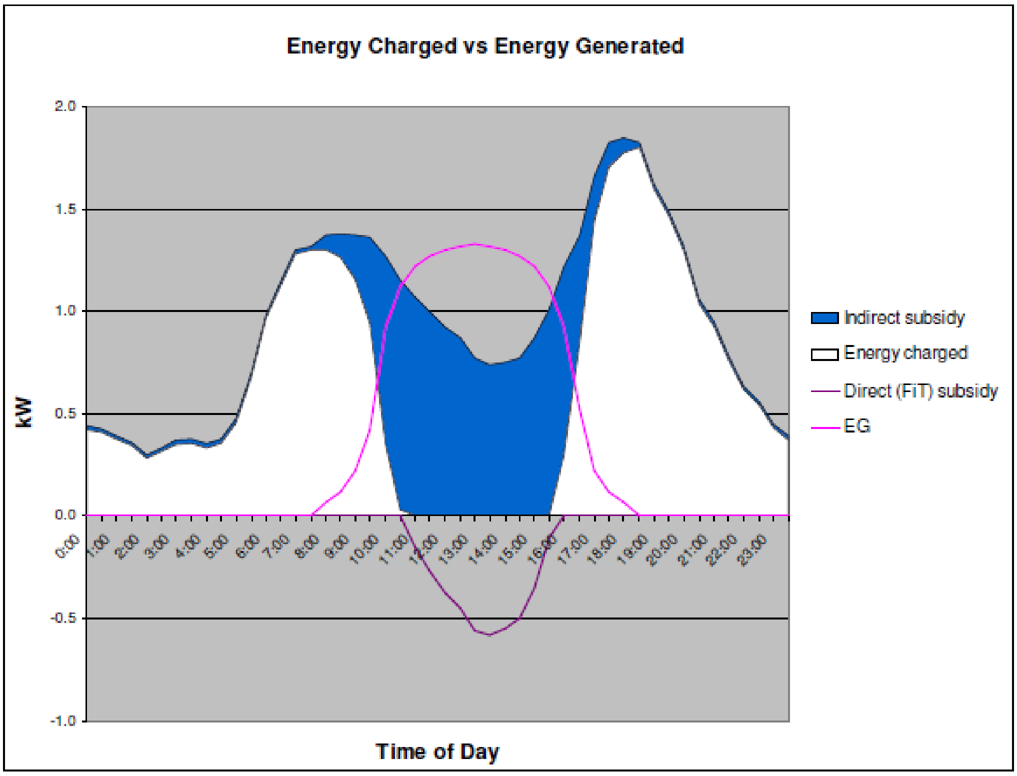


Figure 13 Cross-subsidy as a result of PV net metering

The DNSP will recover these predominantly sunk costs by charging slightly higher rates across the whole customer base. Citipower/Powercor estimates this cross-subsidy to be more than $8m in 2013 across their network of approximately 1 million customers. It is noted that the additional cost of dual element meters (around $12 per meter than single element) is small in comparison to this cross-subsidy, especially if gross metering is only mandated for new installations.

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