Experiences with Residential Grid-Connected Photovoltaic Systems in Australia

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Abstract

Over 6 MW of grid-connected PV has now been installed in Australia. Most of this is on individual homes across the country and purchased directly by the home owners or, in cases such as the Newington Solar Village, pre-installed as part of the house design. This paper reports on consumer experiences, costs and actual PV performance from several residential grid-connected PV systems installed over the past decade, in light of the Australian PV industry's interest in stimulating this market. Comment is also made on issues arising, including consumer information and system ratings, peak load contributions, temperature implications and long term greenhouse abatement potential.

1. INTRODUCTION

The installation of grid-connected photovoltaic systems is booming in Europe, Japan and the USA; so much so that a shortage of silicon wafers is now causing problems with supply and price. In Australia, this market sector has grown at a comparatively moderate rate, driven largely by the Australian Government's PV Rebate Program, and, to a small degree by utility Green Power programs and the Mandatory Renewable Energy Target. Over 6 MW of grid-connected PV has now been installed in Australia (Watt, 2006). Most of this is on individual homes across the country and purchased directly by the home owners or, in cases such as the Newington Solar Village, pre-installed as part of the house design. These homeowners have a variety of reasons for choosing PV for their home. Some analysis of consumer reasoning has been done, for instance by SEDA (2004) and by the NSW Department of Planning (Reidy & Partridge, 2006).

This paper reports on consumer experiences, costs and actual PV performance from several residential grid-connected PV systems installed over the past decade. These include PV performance data from one of the authors' own home in Mudgee (NSW), and an evaluation by the NSW Department of Planning for Newington (Watt et al, 2006). A number of issues need to be addressed if the Australian PV industry is to successfully stimulate this PV market. These include provision of consumer information and evaluation of system rating (including temperature impacts), and PV's potential to contribute to long-term greenhouse abatement and offset peak load. The somewhat conflicting expectations of owners (maximisation of revenue/kWh) and utilities (reduction of network peak load) must also be taken into consideration.

2. GRID CONNECTED PV INSTALLATIONS IN AUSTRALIA

2.1. The PV Rebate Program

The Australian Government's PV Rebate Program (PVRP) has been instrumental in establishing a market for grid-connected PV in Australia. By 2005, the PVRP contributed to approximately 88% of grid-connected PV being installed. Since the start of the programme in 2000, more than 7000 systems, using 8.65 MWp of PV, have been installed (AGO, 2006) and rebates of over AUD 35 million have been provided (Watt, 2006). Of these, more than 3,000 systems were grid connected, using a total of 4.6 MW of PV. The grants have been reduced over time from $5,000 per kW to $3,500. Approvals for grid-connected systems overtook those for off-grid systems by mid 2002, as shown in Figure 1, and now account for the majority of PVRP installations. Over 300 systems have been installed on community buildings, including schools, thus providing a good public profile for PV.

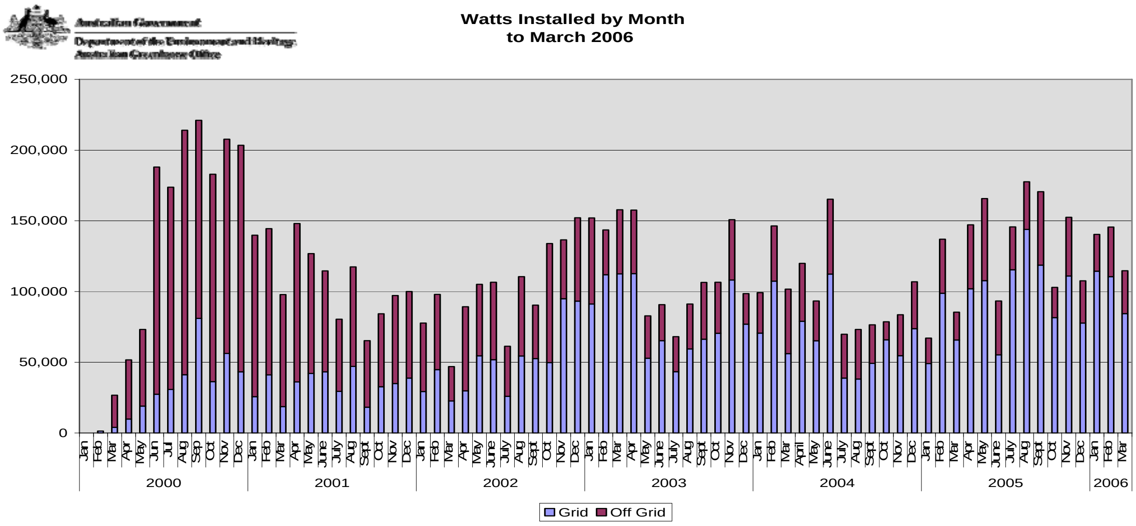

Figure 1: PV installed under the PV Rebate Program (AGO, 2006)

2.2. System Cost Trends via BP Solar's Envirocashback database

BP Solar, through its Envirocashback scheme, gathers large amounts of system data. Analysis of these data shows that for most States the costs of a grid-connected system has decreased since 2003. Only in QLD has the average system cost per watt increased. Across all States the average system cost in dollars per watt has decreased from $13.05 in 2003 to $11.89 in 2005. This represents an 8% decrease on 2003 costs, despite world PV module price rises over that period. Over that time, domestic electricity tariffs have increased by more than 15% for the household monitored here, and are expected to continue to increase at 5% per year above CPI (IPART, 2005). A breakdown of average PV system cost by State and by year is provided in Figure 2.

3. EXPERIENCES WITH RESIDENTIAL PV SYSTEMS IN NSW

3.1. Analysis of a 1.6 kW System in Mudgee, NSW

A 10 panel BP Solar "Solar Energiser" array consisting of 10 x BP Solar 3160 modules connected to a SMA 1700 inverter was mounted on a north facing Colourbond roof at a tilt angle of 25 degrees. A reference cell, ambient temperature probe and module back surface temperature probe were installed to gather meteorological information. Performance data are gathered via a SMA Sunny Boy Controller at 5 minute intervals. Data have been gathered since January 2004. The availability of on-site meteorological data enables normalised performance indicators such as performance ratio (PR)[1] to be calculated, thus benchmarking this system against others.

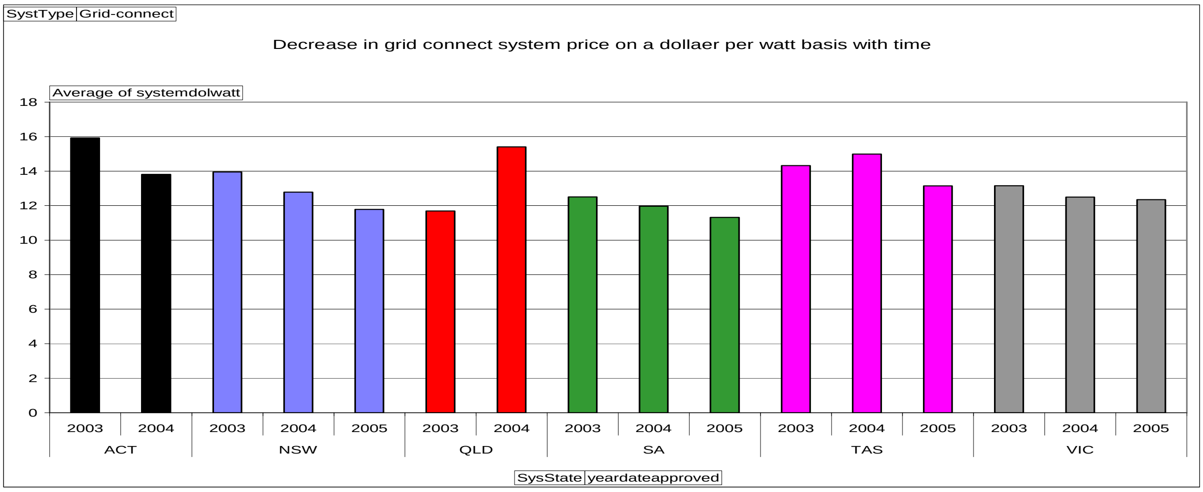

Figure 2: Cost trends in $/Wp from 2003 to 2005 for grid-connected PV systems by State from the BP Solar Envirocashback program.

The system procurement and installation process were straightforward, with a contract entered into with the system supplier, BP Solar, for the Renewable Energy Certificates, and with Country Energy for permission to connect and for net metering. The system was installed by a single installer over a day and a half in November 2003 and has operated without interruption since then. Detailed manuals were provided on the system (including anticipated output), the inverter and subsequently the monitoring system. Information was also included on efficient electricity use. Simple maintenance procedures were explained, comprising inspection for corrosion and loose fasteners, avoiding shade, cleaning modules, if necessary, interpretation of warning lights on the inverter and checking that performance is within the expected range.

The monitoring system can store up to 6 weeks of data. The data are downloaded to a computer by the owner at regular intervals. The monitoring software automatically stores data by month and by year, and also provides an annual summary.

3.1.1. Analysis of system performance

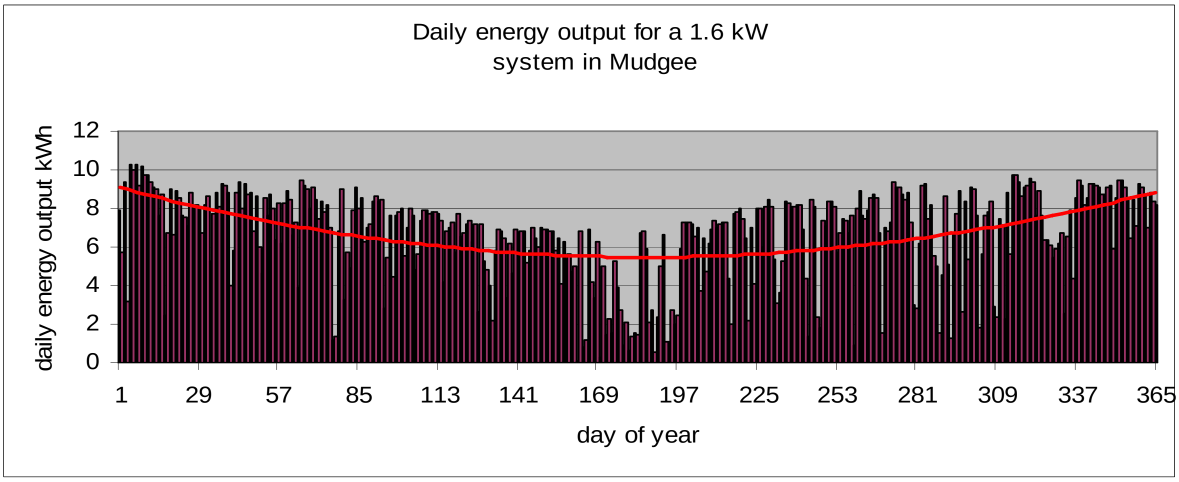

Figure 3: Daily total and trend (red line) energy output, peaking at 10.28 kWh and averaging 6.65kWh per day for 2005.

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[1] The performance ratio equals the actual kW PV output divided by the kW in-plane irradiance theoretically available to the array.

Figure 3 plots the daily total AC energy output and the trend over the entire year. In 2005 the system produced 2426 kWh of AC energy or 1515 kWh/kWpeak, based on name plate ratings (1.6kW). Based on the actual installed power of 1.571 kW[2], this increases to 1545 kWh per kWpeak and compares favourably to the ORER published rate of 1382 kWh / kWp for this zone (ORER, 2006).

On average each day yielded 6.65 kWh of AC energy with a maximum of 10.28kWh produced on the 7th of January. It can be seen from Figure 4 that the 7th of January was clear with consistent irradiance and some evidence of a cooling breeze, due to the moderate maximum ambient temperature of 28.3 ºC. No wind data are gathered by the system.

Modelling of the system using the SMA freeware Sunny Design v1.3 resulted in a predicted annual output of 2202 kWh which correlates well with the 2426kWh actually produced.

Table 1: Daily energy statistics for 2005

Month	**Sum**	**Ave**	**Max'**	**Min'**	**Std Dev**
1	251.81	8.12	10.28	2.49	1.83
2	216.86	7.74	9.37	3.96	1.51
3	221.99	7.16	9.47	1.21	2.17
4	208.36	6.95	8.62	2.80	1.44
5	186.18	6.01	7.36	2.19	1.37
6	114.11	3.80	6.91	0.05	2.32
7	148.88	4.80	7.33	0.51	2.42
8	197.18	6.36	8.42	1.37	2.16
9	206.97	6.90	9.35	0.92	2.24
10	201.72	6.51	9.30	1.30	2.60
11	211.53	7.05	9.74	2.29	2.23
12	261.20	8.43	9.49	4.39	1.16
-	**2426.78**	**6.65**	**10.28**	**0.05**	**-**

The close correlation between measured and predicted energy delivery demonstrates that predicting energy output from optimised arrays using good quality, reliable system components is possible. The system described here has had an availability of 100% and it is this reliability that is of paramount importance if energy outputs are to meet customer expectations.

The Kogarah study (Energy Australia, 2005) reported several inverter failures that were undetected for some time and this contributed greatly to the low overall energy output. Similarly, in the Newington analysis reported below, 2 of the 30 homes monitored had faulty inverters.

Note that should 1 week of generation be lost due to equipment failure during January or December in Mudgee, this would equate to an energy loss of 2.3% over the year. This highlights the need for reliable components and a prompt response to failures. It should however be noted that, assuming a utility buy back rate of 12 cents per kWh this represents a loss of revenue of only $7.00.

Figure 5 shows the PR of the Mudgee array for the months of December 2005 and June 2005. The effect of temperature on the system performance is clearly visible as is the lower daily insolation of June compared to December. For both months the average daily PR is 70% - a figure that indicates good overall system performance, with a daily maximum of 74% in December and 78% in June.

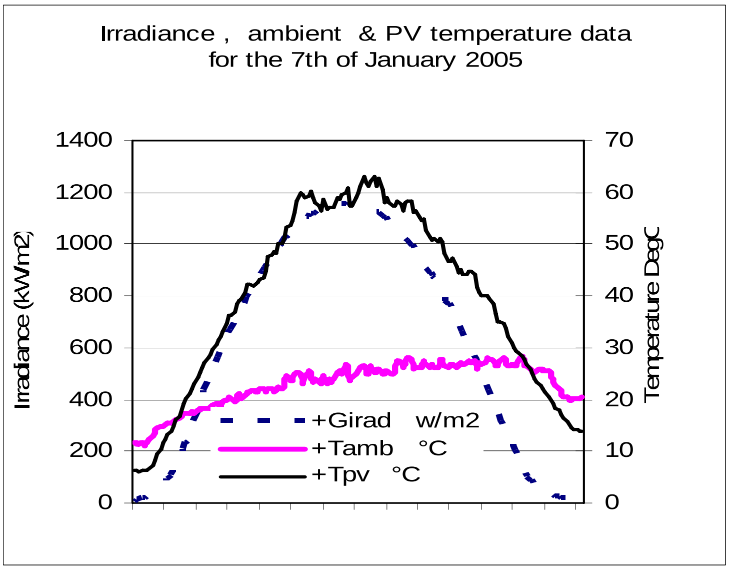

Figure 4: Irradiance and temperature (ambient and PV) on 7th January 2005.

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[2] The actual power installed differs to that stated on the nameplate of each modules due to manufacturing tolerances. Typically manufacturers state this tolerance as a % e.g 150 +/- 5%

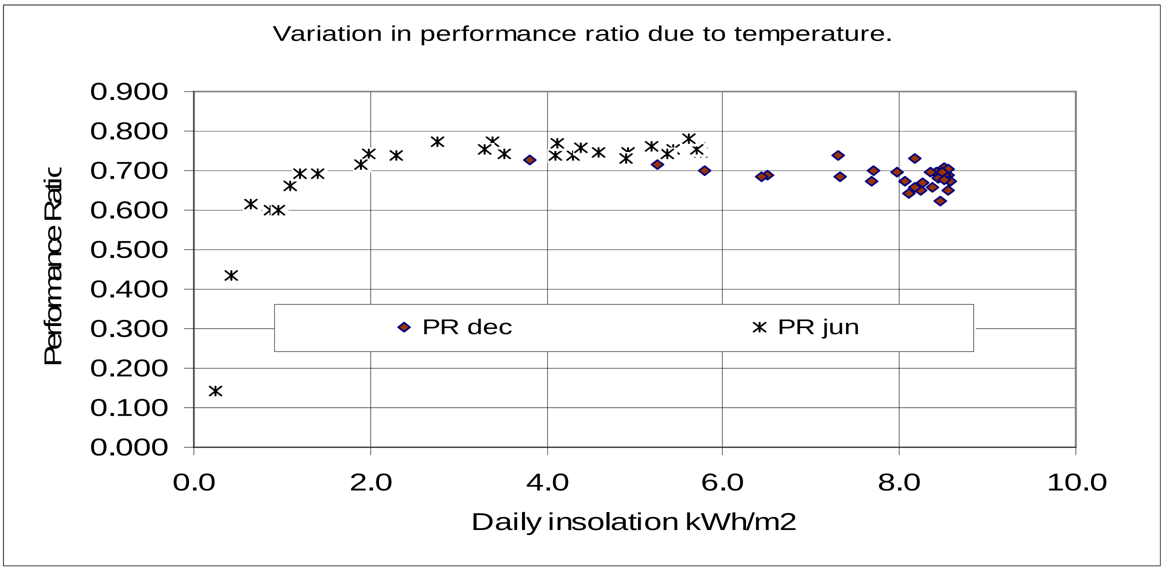

Figure 5: System Performance Ratios at different insolation levels in June and December showing reductions in December due to increased array temperatures.

3.2. 1 kW Systems in Newington (from Watt et al, 2006)

3.2.1. Background

As part of the planning process for the 2000 Sydney Olympics, the organisers agreed to create a “green” village and environmentally sustainable facilities. The Athletes Village was purpose-built as an energy and water efficient medium density development with a mix of free-standing homes, apartments and community facilities. It was part of the new suburb of Newington and some of the houses were used to accommodate Olympic athletes during the Games and then sold. All free-standing homes are equipped with PV systems and solar water heaters. By 2004, 780 homes had been built with 1000 Wp of PV each and 199 houses with 500 Wp each. Passive solar design features, energy efficient appliances and grey water systems are also used in all homes. These were expected to reduce net energy and water requirements significantly compared to standard Sydney households.

Although it was generally promoted as a Solar Village, the design and marketing of the Newington homes was more circumspect with regard to their energy efficiency and solar features. The solar arrays, although not totally hidden, were generally roof integrated and placed discretely so as not to be too visible from the street. The homes were purposely marketed to the general home buyer, not to the ‘energy aware’ or ‘green’ customer market. The energy features were part of a total home package and purchasers may not necessarily have been especially interested in them.

With the suburb now well established, the NSW Department of Planning monitored a selection of the homes as part of its electricity demand management activities, in order to assess the overall impact of the sustainable energy measures used, as well as the effectiveness of the PV systems in minimising peak loads on the grid. Data on electricity use and PV output were collected from 30 homes with 1kW PV systems over 12 months from the beginning of July 2004 through to the end of June 2005. The results are reported in Watt et al (2006). The data consisted of half hourly PV output, with import and export of electricity from the grid measured separately. This allowed assessment of the overall impacts of urban-scale use of PV on the network, examination of the variability between different houses, together with any correlation between PV output and load. The household load and PV output profiles were compared to half hourly loads at the local Homebush Bay zone substation and the National Electricity Market (NEM), as well as NEM spot prices and ambient temperatures in the Sydney Olympic Park area.

3.2.2. Newington PV Performance

The average daily PV output per house was 3.16 kWh, or 19.6% of consumption. Two of the PV systems were found to be faulty, one not operating at all, the other showing very low output. The householders are either unaware that the systems are not operating, or have not bothered to access their system warranties. Thus, for the operating systems, the annual average output was 1234 kWh, which is slightly lower than the ORER published rate of 1382 kWh / kWp for this zone (ORER, 2006).

The 30 Newington systems have a PR of 0.61. If the two non-functional systems are removed from the data, the remaining 28 systems have a PR of 0.65. This compares with international averages of 0.70 for systems installed after 1996 (PVPS Task 2, 2005) and 0.70 shown above for the Mudgee system. Hence the Newington systems are performing below the average range. Temperature de-rating of the PV panels, which are recessed into the roofline, may be responsible.

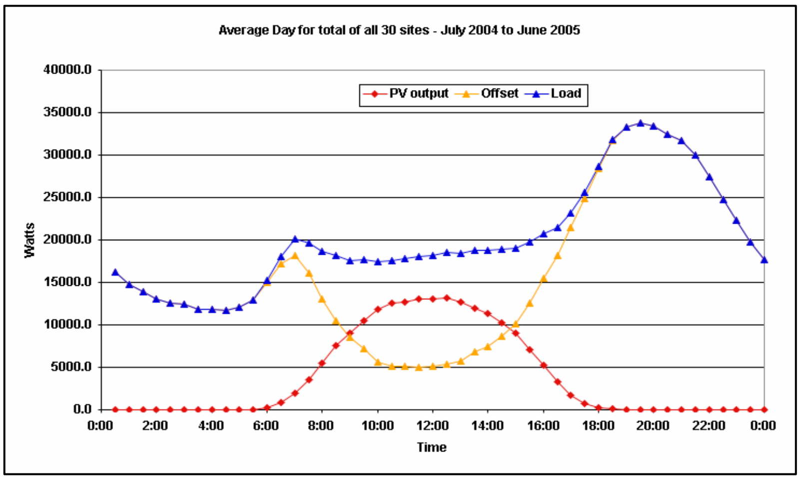

Figure 6: Annual average Household load, PV output and resultant load for 30 Newington homes

The PV average maximum contribution occurs between 10:00am and 2:00pm, whereas the average Newington residential load peaks between 6:00pm and 10:00pm. Thus PV makes the Newington residential peaks, as seen by the network, even more distinct. The passive solar design of the Newington houses exacerbates this problem as it reduces the need for midday cooling. Conventional houses are likely to have a higher midday load if air conditioning if installed. Load from the 30 Newington homes is also very peaky, with the load being greater than about half the maximum for only 5% of the time. PV changes this very little; the main impact is to offset the load when it is very low which results in export to the grid at these times. Ten of the top 20 peaks occurred on Sundays. The peak loads on all these days were late in the afternoon, when PV could not contribute. Figure 6 shows the average load and PV contribution over the whole year.

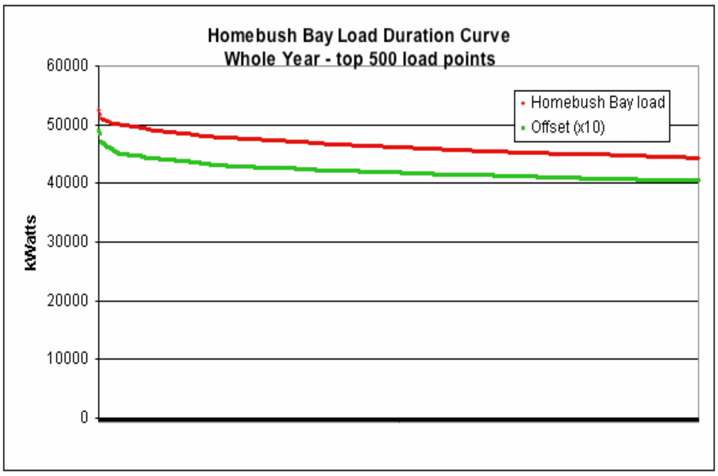

Figure 7: Load duration curve for Homebush Bay substation for the top 500 load points July 2004-June 2005, showing the offset possible from 10X the PV currently installed

Newington is serviced by the Homebush Bay substation, which has a large industrial and commercial load and a corresponding peak load between 11am and 2pm, which allows PV to align well to overall network load. The 30 monitored sites were assumed to be representative of the total installed PV at Olympic Park which feeds into the Homebush Bay substation. Figure 7 shows the load duration curve for the top 500 load points at the substation, with the resultant load as reduced by PV output. To make the contribution by PV to offsetting the total Homebush Bay load more obvious, the estimated Olympic site PV output was multiplied by 10. It is clear that, in addition to reducing energy and losses, the PV reduces peak load right up to the very highest load points. The 3.4 MW reduction in the highest load point means that 29.5% of the assumed 11.54 MW (10x current PV) was contributing directly to offsetting the peak load.

There is little general correlation between either PV output or residential load and NEM spot prices, although there is an occasional coincidence of high load and high spot price.

4. PV PERFORMANCE AND ISSUES RAISED

4.1.1. Conflicting expectations and objectives.

With buy back rates varying from as little as 4 cents per kWh to the more typical 12-14 cents and minimal (zero!) reward given at present to PV systems for their contribution to minimising peak loads on the grid through power generation at peak times, a conflict in interest and expectations may arise.

For net metered systems, where the import rate equals the export rate, the system owner is encouraged to maximise the PV system's output. Thus, in the absence of a reward for generation at particular times, PV arrays should be configured to maximise annual energy output and PV revenue ($291 annual in the Mudgee case assuming 12cents per kWh).

Whilst many have reported the potential network benefits of using PV as distributed generation near the points of end-use, in addition to the benefits when the PV profile matches peak demand (BCSE, 2003, Watt, 1997), there is no incentive at present for the PV owner to maximise grid benefits. Indeed a customer who orientates their array at an azimuth of North West, in order to delay peak power generation to better match peak utility demand, is at present reducing the annual energy output from their system by approximately 4% (1332 kWh/kWp compared to 1382 anticipated for a North facing array) with no compensation. For arrays facing West the reduction is approximately 13% (1199kWh /kWp), using figures calculated by Sunny Design.

It could be argued that net metering provides a general incentive for PV installation, since the rate paid is higher than that which would normally be paid for power purchased by the electricity retailer, even including network costs. Nevertheless, as shown for the Newington PV systems, a significant reduction in substation peak load can occur due to PV installations, with benefits to both the retailer and the network service provider. Perhaps it is this split of benefits, compounded by the lack of a carbon price in the Australian electricity system, which makes the case for grid-connected PV more difficult to argue than it appears to be in other countries. In this context it is interesting to note that electricity retailers are moving away from net metering in any case, so that many PV system owners are now being offered rates closer to bulk supply rates for exported electricity. This is in sharp contrast to the international trends to high feed-in tariffs for PV, which have now been adopted in 41 state or country jurisdictions (REN21, 2006).

4.1.2. System performance and customer expectations

Failure of system equipment, especially if undetected, can certainly contribute to customer expectations not being met. A more common situation, however, is that systems are operating but not at their optimum. In these cases the owner is often unaware of the situation, especially if inverters are in locations with poor access, such as attic voids and no remote display is available. Net metering and a lack of accurate weather data can contribute to this ignorance.

It is feasible, however, with knowledge of basic system parameters, to validate that the inverter is tracking the maximum power point of the PV array. With knowledge of the open circuit voltage of the system and the ambient temperature, basic system performance can be calculated.

Each module has a typical open circuit voltage of 44.2 volts, with a maximum power point voltage of 35.1 (typically Vmp is 80% of Voc). Thus with knowledge of the module voltage when producing power, and its temperature, it is simple to ascertain whether the system is operating at its maximum power point.

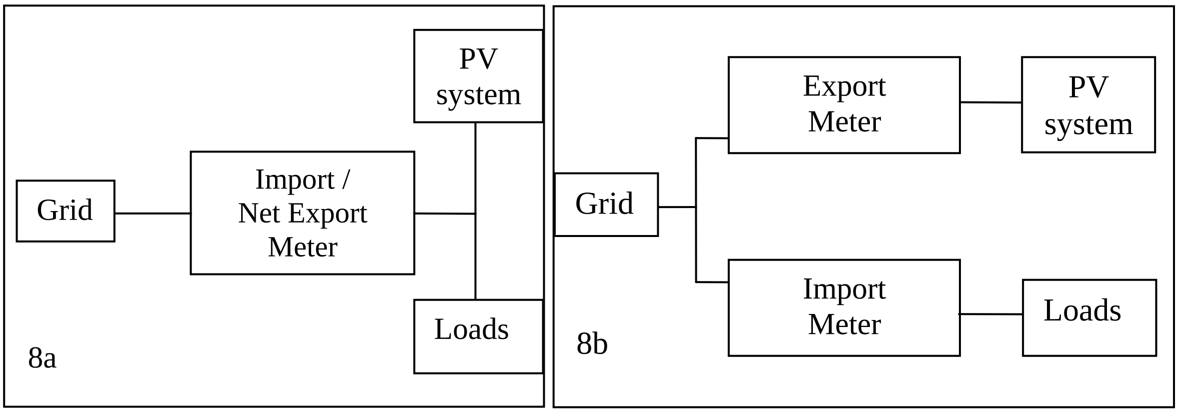

Figure 8. Using a net export meter [8a] conceals PV system performance from the user if inverter performance data are not readily available whilst [8b] enables non optimum system performance to be more easily detected.

For instance with the Mudgee array operating at 50 °C and knowing that the open circuit voltage falls by 2.2 mV / cell / °C we would expect the system voltage at this instant to be:

$$[5 \times 44.2 - [5 \times 72 \times 2.2\times10^{-3} \times (50-25)]\,] \times 0.8 = 161 \text{ V}$$

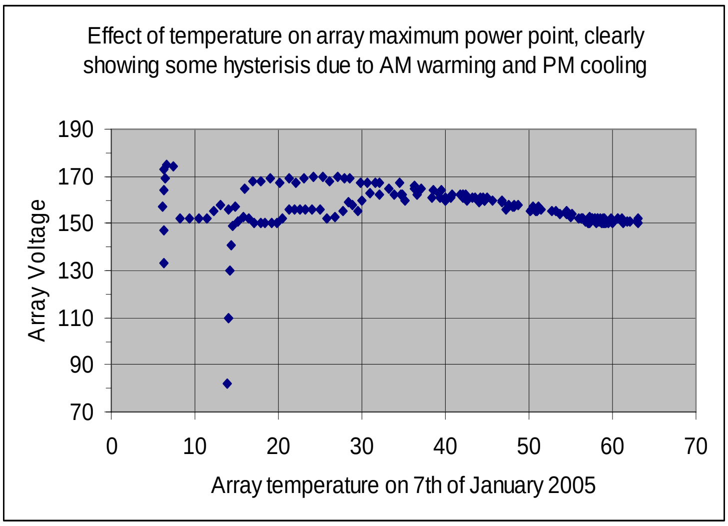

Figure 9: Effect of temperature on the maximum power point voltage

Good correlation is achieved with the observed system voltage for the 7th of January 2005, as shown in Figure 9. However, even this level of assessment requires access to data which may not be available to the system owner. In practice, it may be useful for system owners to be provided with a simple table showing the output range which should be expected at various temperatures, with assumptions built in as to the relationship between array temperature and ambient temperature. This may provide a simple means of checking whether or not the system is operating correctly. If the output appears to fall outside the given range, a simple maintenance checklist could be used, with a maintenance call as the final option.

Without some indicator of system output, however, even this simple check cannot be undertaken.

A common fault in relation to temperature in the author's (2) experience is that systems are designed incorrectly – in some cases insufficient DC voltage is present to allow the inverter to begin tracking the maximum power point. This problem is amplified during warm weather at high irradiance levels where the system voltage reduces further from nameplate by 0.0022V/cell/°C (equating to 4.8V per 72 cell module assuming a 30°C temp rise above standard test conditions). In some cases the inverter may "bottom out" or "flat line" on the power voltage curve and thus operate at a non optimum point of the array's power–voltage curve.

Interestingly, of the 4157 hours of data logged in Mudgee for 2005, the array temperature was greater than 50°C for 23% of the time, greater than 60°C for 8% and greater than 70°C for only 0.4% of the logged time. From these data it would seem reasonable to configure systems for correct operation in temperatures of at least 60°C. It may also be useful to provide output figures assuming these likely higher temperatures under Australian conditions. For the Mudgee system, the rated temperature of 25ºC is exceeded 66% and the NOCT temperature of 47ºC is exceeded for 29% of the time.

Care must be taken however not to exceed the input voltage ratings of inverters as this will, in the majority of cases, lead to non–warrantable damage. Whilst connecting more panels to the inverter to increase energy production may be the intention, this action may not always meet the expectations of the customer.

5. CONCLUSIONS AND RECOMMENDATIONS

Grid-connected PV systems are just beginning to become an established market in Australia. Over 6 MW is now installed, but the potential market is very large, given Australia's excellent solar resources, our high level of grid connection, our high level of individual houses and high home ownership rates. With a minimal level of system checking, it is possible to ensure high system availability and good performance ratios. The high daytime temperatures experienced in many parts of Australia indicate a need to ensure appropriate system design, wiring and component placement. The PV systems reported on in this paper each displace between 1.3 and 1.6 tonnes of CO_2 per kWpeak per year and could be expected to do so for 30 years or more. Increased uptake of grid-connected PV could therefore play a useful role in reducing Australia's greenhouse gas emissions. Alternative support structures, which provide more incentive to maintain high output and reduce greenhouse gas emissions would assist in future market development. The following recommendations are made:

Meeting customer expectations is critically important if this market is to meet its potential. Customers need clear and easy-to-understand information which explains key aspects of system design and expected performance. This should include maintenance checklists, expected output at different temperatures and the significance of aspects such as shading, dust build-up, loose connections and inverter over-heating. This information should be discussed and explained, not merely included in a manual. Preparation of video/DVD based information should be considered. Important in all this is the ability of owners to see what the system is doing, so they can assess whether or not it is operating correctly. Readily accessible displays on the inverter, or remote display panels should be encouraged. The establishment of a PV owners' network could also be useful, as could an email or telephone-based help line. While the market is small and customer information and understanding are low, the exchange of information and experiences amongst system owners may play an important role which supplement's information provided by the installer. It will of course bring out the gripes and general negative feedback, but this is also important for the industry, in order to keep improving its systems and its customer service.

Metering and tariff issues are set to become more complex with the rollout of interval meters and increased retail competition. Net metering was initially offered to the majority of small PV system owners, but many electricity retailers are backing away from this, with new customers being offered less favourable buy-back rates. In addition, the interval meters typically being installed do not have a spare channel with which to record PV output, so that a second meter is likely to be required, making net metering less likely to be offered. Internationally, net metering is often mandated for small PV systems while increasingly, high buy-back rates or 'feed-in-tariffs' are offered in order to encourage PV installation. Providing support for PV via high buy-back rates, rather than via up-front capital grants, has the advantage of encouraging system owners to make sure their systems are performing optimally at all times. This in turn encourages installers to provide maintenance contracts and longer warranties, while also placing more pressure to reduce up-front costs, since these are not subsidised. International analyses (eg Carbon Trust, 2006) have also found that feed-in tariffs can provide a more cost effective means of technology support than more generic mechanisms such as MRET – not only because they can target specific technologies, but because the tariff can be adjusted as prices change and can also be varied by location, for instance, to encourage PV in grid-constrained areas that have an appropriate load profile. From the Government's point of view, a feed-in tariff model should provide more certainty that the systems supported are working and hence that funding provided is actually delivering the greenhouse gas benefits promised. Net metering should be the minimum level of tariff support provided in order to encourage grid-connected PV installations in Australia. Higher feed-in tariffs should be considered, at least in critical locations.

While crystalline silicon modules make up the major portion of PV installed, operating temperature will remain important. Adequate ventilation of modules is even more important in Australia than it is in the colder climates of Europe and Japan, where the majority of grid-connected arrays have so far been installed. The way modules are connected can also be important, with horizontal rather than vertical connections minimising temperature differentials between interconnected modules. Similarly, inverter placement to minimise heating is important as the inverters will also de-rate at high temperature. Placing inverters in a metal enclosure on a west-facing wall is therefore not recommended.

Finally, the introduction of a carbon price into the Australian energy market is urgently needed in order to provide the overall market signal necessary to encourage a re-think of Australia's energy supply and demand and a transition to a low carbon future.

6. ACKNOWLEDGMENTS

Access to the results of the Newington Solar Village study from the Demand Management and Planning Project, NSW Department of Planning and to the Envirocashback data from BP Solar is gratefully acknowledged.

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