Using PV to meet Peak Summer Electricity Loads

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ABSTRACT

Until the last decade, peak electricity loads in Australia were mostly in winter. In many States peaks are now in summer and are growing rapidly, with one of the main contributing factors being the increase in use of air conditioning.

South Australia has the "peakiest" load pattern. The ratio of average to peak load in South Australia has fallen from around 60% to 50% over the past few decades, resulting in increasingly inefficient use of costly transmission and distribution assets. In a recently monitored new subdivision in Adelaide, 50% of the distribution feeder maximum load was only exceeded for 5% of the year. This trend is evident in other areas with high housing growth rates such as Western Sydney, where 10% of the system capacity is used for only 24 hours a year. At the same time, spot prices in the National Electricity Market during major summer peaks can be very high with associated cost implications for electricity retailers and hence for customers. AGL South Australia has introduced a summer tariff, which currently is set at 20.944 c/kWh for day rate consumption above 3.3 kWh/day, 10% higher than the standard tariff.

This paper will examine the potential for PV to contribute to peak summer loads in a number of locations with different load characteristics. It will also examine the implications of temperature and orientation on PV performance at peak times. The results will be used to analyse the value of PV to electricity network operators and retailers in managing their summer peak load problems in future years.

1. INTRODUCTION

Although the use of PV for grid connected applications has grown rapidly internationally over recent years, the market in Australia is small and still largely dependent on government grant programs. With Australia's relatively low, uniform electricity tariffs, PV does not appear cost effective for grid applications as its output is valued only on the basis of total kWh generated over a year. However, despite the uniform pricing signals given to most retail customers, the generation and delivery of electricity is not at uniform cost. The use of electricity is growing rapidly, the peak load in many states is now in summer and the electricity industry is set to spend billions of dollars over the next decade in new generation plant, including significant expenditure on peak load plant, and on new and upgraded network assets. There are opportunities for PV and other demand side measures to contribute to point of use energy supply, thereby reducing the need for central generating plant and for costly network upgrades. To do this, however, the wider benefits of distributed PV generation need to be valued. This paper examines the potential matching of PV generation to summer peak loads, in a preliminary attempt to fully value the benefits of PV to Australia's electricity system.

2. DEFINITION OF THE PROBLEM

Electricity demand has grown rapidly in Australia over the past decade, spurred by buoyant economic growth, high growth in the housing sector and increased use of electrical appliances, such as computers, dishwashers, large screen televisions and reverse cycle air conditioners. This high overall growth has been accompanied by an exacerbation of the "peakiness" of electricity demand patterns. The latter is highly correlated with temperature extremes, both summer and winter (CRA, 2003, Oliphant, 2003). This is clearly illustrated in Figures 1a and 1b.

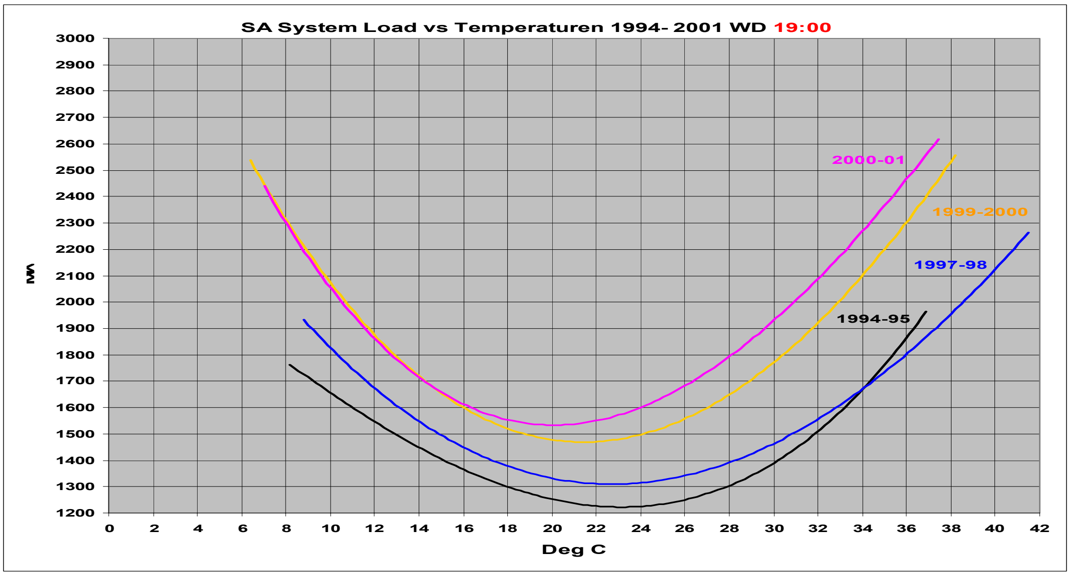

Figure 1a: South Australian System Load vs Temperature, Weekdays at 19:00, 1994 -2001 (Source: Oliphant 2003)

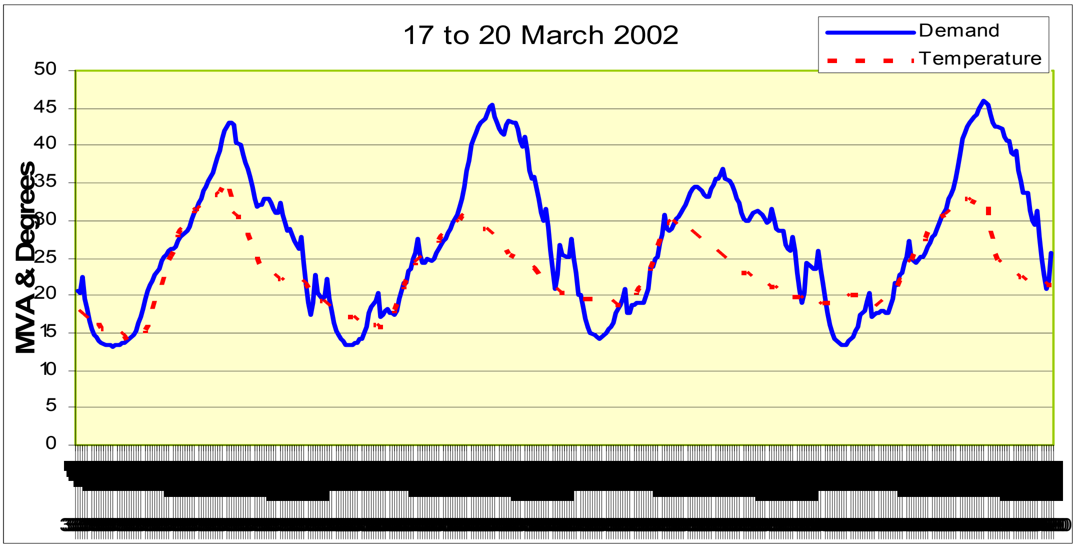

Figure 1b: Temperature and Demand on Peak days in Western Sydney (Source: Integral Energy)

The summer peak is rapidly overtaking the winter peak in most states and is compounded by the effective derating of network assets and gas turbines when ambient temperatures are high. Poor power factors attributable to air conditioner use exacerbate the problem. The system peak on Integral Energy's network is now around 3500 MW on a hot (44 deg C day) compared with a peak below 2500 MW on a normal (29 deg C) day (ibid). 383 MW of Integral Energy's peak demand appears for just 25 hours a year. This "needle" peaking problem is accentuated for feeders with high residential or commercial loads but is not so pronounced on feeders with high industrial loads or time of use customers (ibid).

Similarly in South Australia, the peak load has been growing at around 90 MW per year since 1996. At the same time there has been a decline in load factor, (ratio of average load to peak load), from about 60% in the 1970's to less than 50% in 2001 (SA DSM Taskforce, 2002). The South Australia load duration curve is the "peakiest" in Australia, as shown in Figure 2, with increased air conditioning load considered to be the major cause. In some new residential subdivisions in Adelaide, 50% of local network capacity is now used for only 5% of the time. It is also evident that the cooling load is cutting in earlier in the day, or at lower temperatures than in the past, perhaps because of automatic, thermostat controlled systems and an increased expectation of cooling (see Figure 1a).

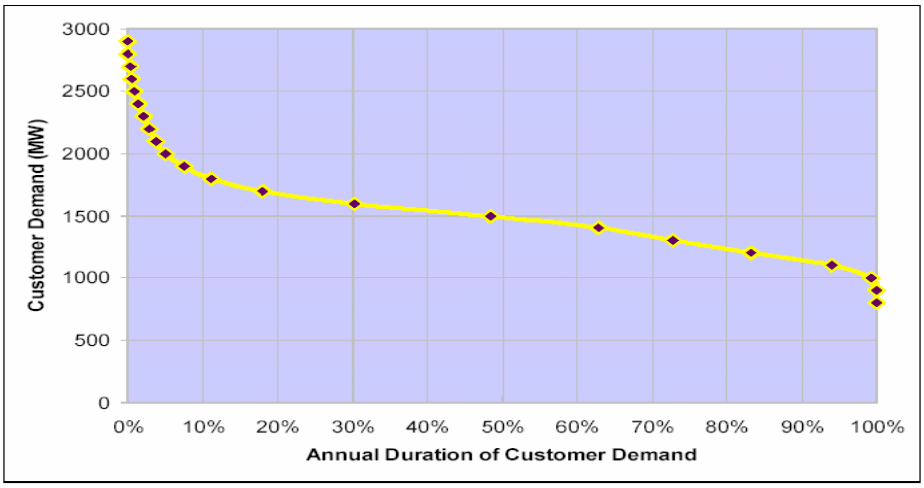

Figure 2: South Australian Load Duration Curve
(Source: SA Government Task Force, 2001)

A large portion of this peak load growth, as well as the trend towards summer peak loads, has been driven by the rapid increase in residential and commercial air conditioner installations. Integral Energy estimates that these contribute 70% of the needle peaks, with new residential estates exhibiting a peak to off peak ratio of 5.5 to 1, compared with a 3 to 1 ratio for older suburbs (CRA, 2003). Integral has now almost doubled its load estimates for new houses from 3.5 to 4 kVA peak to 6 – 7.5 kVA peak (ibid). Overall load growth, and particularly peak demand, is now driving significant levels of investment in new generating plant ($5 billion this decade) and in new or upgraded transmission and distribution network capacity ($8 billion this decade) across the country (Nethercote, 2003).

Most of the new houses built over the past decade have taken little or no consideration of energy efficiency. Orientation of houses on a block is purely on the basis of maximizing the number of blocks in a subdivision and does not consider solar access. The trend has been to remove eaves and provide larger living spaces instead. Similarly, verandahs are now rare. Block sizes are small, so that tree planting, which might allow external shading of windows is not possible. Large feature windows, often with no curtains or blinds are common. Air conditioning is offered by builders as a special deal with certain mortgages and, obviously with the type of houses being constructed, is a necessity. Some Councils have begun to introduce energy efficient design criteria and some State governments are attempting to bring in minimum performance standards. However, governments at all levels are extremely sensitive to issues in the housing sector and are often unwilling to potentially jeopardize developments or increase initial costs. There has been considerable opposition from the building sector to the recent Victorian proposals for house energy ratings, despite earlier agreement that a level playing field would be preferable. In areas with the highest housing growth rates, such as Western Sydney, little has been done to encourage energy efficiency. This will leave a legacy of poorly performing housing for decades to come.

Recent summer peaks in South Australia, Victoria and NSW have resulted in supply disruptions and, on some occasions, extremely high spot prices on the National Electricity Market, as shown in Figure 3. This is now an issue for electricity retailers and may cause a trend towards summer peak tariffs, as is already occurring in South Australia, where AGL has introduced a summer peak tariff of 20.944c/kWh when daily usage exceeds 3.2877kWh. While this will provide a weak market signal for electricity users, it continues the cross subsidization of high peak load users by other customers and hence will not necessarily reverse trends towards high air conditioner penetration, unless accompanied by other strategies. Management of peak loads is not a new issue for electricity suppliers. Off peak tariffs for loads such as water heating have long been used as a means of evening out load profiles. However, as pointed out by CRA, supply side alternatives to air conditioning are not as readily available as are heating alternatives. On the other hand, demand side measures are now available and have yet to be seriously considered or marketed to customers. Distributed PV is one of these and the opportunities for its use are discussed in this paper.

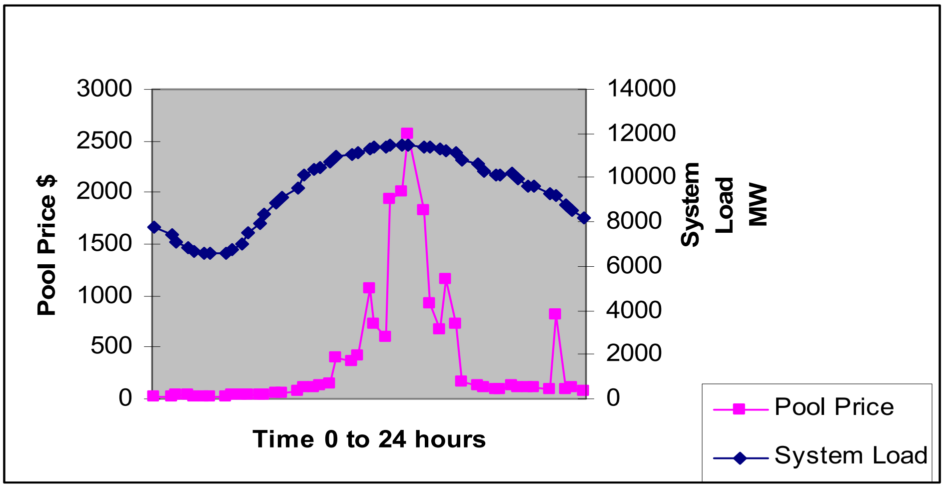

Figure 3: Pool Price vs System Load, Integral Energy 23 January 2001. (Source: Integral Energy)

3. DISTRIBUTED GENERATION AND OTHER DEMAND SIDE SOLUTIONS

As previously discussed, much of the load during high temperature periods is from air-conditioning. Feeders with high air-conditioning motor loads also tend to have reduced power factor. Demand side solutions to these problems may be cheaper and more robust in the long term, than the current attempt to increase and strengthen the supply side. For instance, the increased air conditioning load is most evident in new residential subdivisions. Sensible house design, beginning with no cost options such as correct orientation and appropriate window placement, and extending to insulation and external shading, can play a significant part in reducing the cooling load of a house.

Appropriate tariffs, which signal peak demand periods are used for industrial and some commercial customers. However, aside from a small number of residential customers who have chosen time of use metering, there has been little attempt by the electricity sector to provide feedback via tariffs which might change customer's discretionary electricity use patterns. Related to this has been the debate about metering. Electronic meters are readily available and could be installed in all new houses and when meters are being replaced. This would allow tariff signals to be used for demand management, as well as for encouraging distributed generation (Outhred, 2003). They have been opposed on the grounds of installation and data processing cost. However, we are now facing billions of dollars of costs in new generation, and transmission and distribution system upgrades. While tariff signals are only part of the solution, it is clear from the South Australian PV take-up rate, as well as from the demand patterns of commercial and industrial customers who are billed by time of use, that tariffs can be useful. Appropriate metering is a necessary starting point.

Finally, PV systems can play a role by reducing end use demand, reducing the network load and hence reducing system losses on hot days. These benefits are discussed below. In addition, inverters used to connect PV systems to the grid have the capability to provide reactive power, thereby increasing power factor and hence also reducing network losses.

4. INTERNATIONAL STUDIES

In the early 1990's the US electricity utility, Pacific Gas & Electric Company (PG&E), installed a 500 kWp PV system with the express purpose of measuring network benefits, including peaking value. The system was connected into a semi-rural distribution feeder with a peak summer load at around 4pm. Results of the trials have been reported in Wenger et al, 1994 and are summarized below:

Reliability:	The PV system provided predictable voltage support, reduced customer downtime and delayed the need for network reliability upgrade.

Reduced Losses:	Both energy and reactive power losses were reduced.
Substation:	The transformer operating temperature was reduced both before and during the system peak and hence its capacity was increased. Transformer replacement and load-tap change maintenance were deferred.
Transmission:	Transmission capacity was released and system upgrade deferred.
Load:	The PV system provided 90% of its rated capacity at peak load times and an average capacity factor of 25%.

Overall, PG&E found that taking into account distributed benefits of the PV system doubled its value to the utility when compared with traditional central power station analyses of energy and capacity benefits only. While the actual savings are obviously site specific, the general conclusion that distributed PV systems can provide real network benefits, above their energy and capacity credits, is likely to be valid across many substations in Australia which are currently facing peak summer load constraints. A methodology for assessing the site specific benefits of distributed PV systems for any network, as well as for optimum system placement, is given in Hoff & Shugar, 1995, based on the Kerman results.

A range of non-energy values of distributed PV systems are discussed in a recent IEA report (Watt, 2001). These include results of US studies which have shown PV to have a high dispatchable rating on summer peak load grids (US DoE, 1996) with the potential to increase this even further with strategic load management (Perez et al, 1999). Studies in Japan have found that distributed PV systems can provide smoother output than centralized systems and can provide a better match to loads, thus effectively increasing their capacity value (Ohtani, 1999).

5. POTENTIAL ISSUES

Although the output from PV arrays will be higher in summer than winter, and hence generally of benefit in a summer peaking system, PV output from mono and polycrystalline silicon cells decreases with increasing temperature. For instance, the efficiency of a typical module will reduce by around 0.4% for each degree above 25 °C. Hence, at 45 °C, a module rated at 18% efficiency will only operate at 10% efficiency. Roof temperatures can often be higher than ambient air temperature, further exacerbating this problem, unless measures are taken to ensure ventilation between the roof and the module. The impact of temperature on module performance is shown in Figure 4 where the ambient air temperature on February 7 2001 reached around 37 °C and on February 11 reached 32 °C. Also shown in Figure 4 is the impact of summer haze and cloud, which occurred on February 6th.

Thus, extreme heat, haze and cloud cover which can characterize peak load summer days will result in some degradation of PV system output. The magnitude of the degradation will vary over the day as conditions change and will not necessarily be cumulative over the whole day. Despite the degradation of performance under these extreme conditions, however, load reduction, transformer pre-cooling effects and reduction in system losses will remain significant.

6. PRELIMINARY RESULTS

In order to assess the possible contribution that distributed PV systems could make to alleviation of the issues of energy supply and network constraints on hot summer days, the output of a PV system installed in Adelaide was examined. The characteristics of the PV system, as detailed in Keipert & Oliphant, 1998 and Oliphant, 2000, are:

Installed capacity:	12 x 80W Solarex polycrystalline panels (Total 960 W)
Inverter:	1.3 kVA Omni Star SEA
Installation:	Almost flush mounted on roof in a plastic tray with 5cm air gap for ventilation. Roof faces virtually due north with a pitch of ~ 35 ^{0}
Average Output:	3.2 kWh/day, (since 1999) ie ~1170 kWh/y.

The summer of 2001 was extremely hot and resulted in the highest ever SA system peak load of 2833 MW on 6 February. The peak load only dropped slightly the following day to 2819 MW. Figure 4 shows temperatures and Figure 5 PV output for the days 6, 7 and 8 February as well as for 11

February, when the ambient temperature was lower and the maximum PV output for this test period (4.93 kWh/day) occurred.

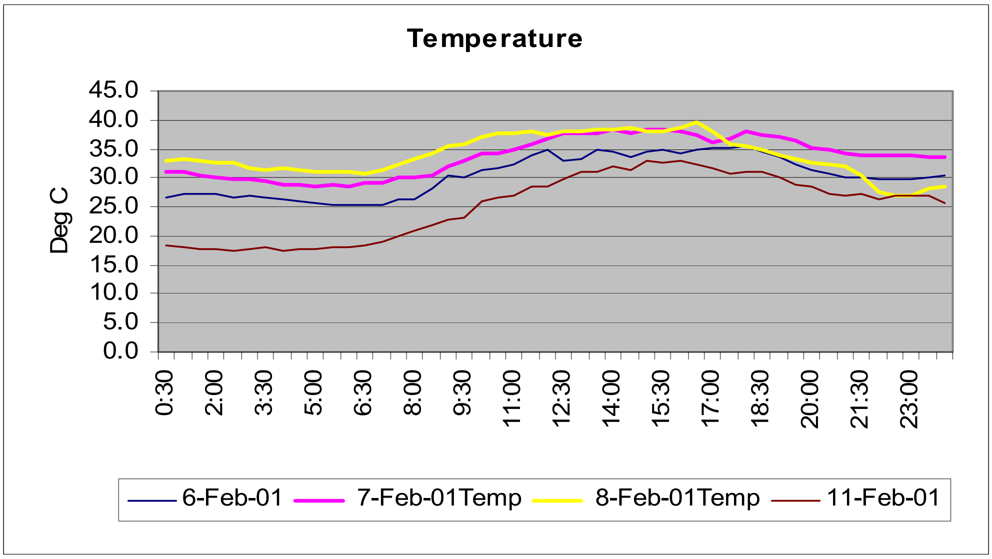

Figure 4: Adelaide temperatures during peak summer in 2001.
(Source: Oliphant, 2003)

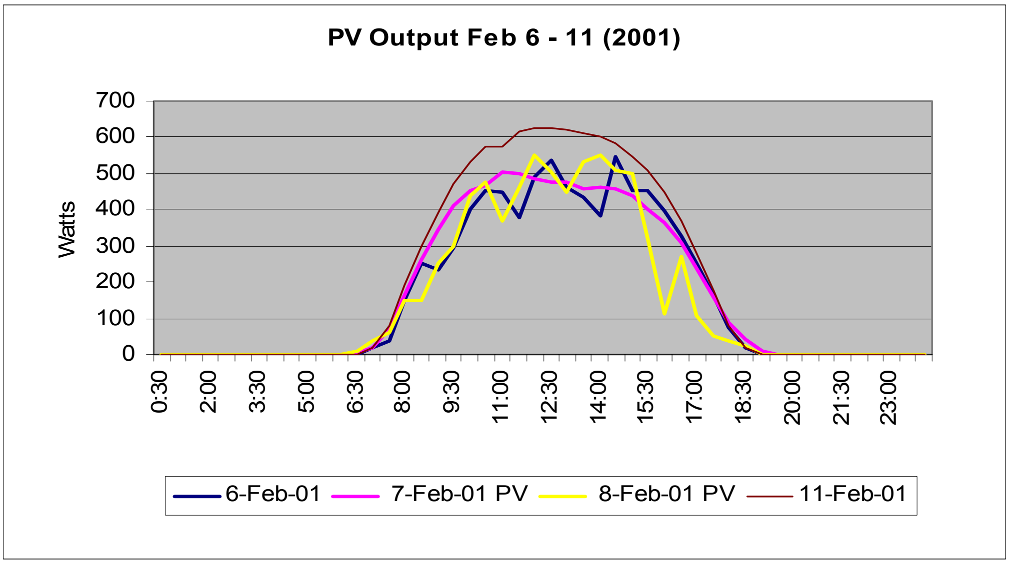

Figure 5: PV Output in Adelaide during Summer Peak Days
(Source: Oliphant, 2003)

It is evident that PV output was affected by cloud on 6 and 8 February and probably by heat on 7 February. On 11 February, when temperatures dropped, PV output was higher, illustrating the temperature dependence of output from crystalline silicon panels.

Figure 6 shows PV output on a peak temperature day against typical South Australian household load. It is evident that PV can reduce residential load from 7:30am and almost to the peak at 6pm. The network benefits of transformer pre-cooling and system loss reductions during the day will also occur and provide additional benefits. Figure 7 shows PV output against typical commercial load and indicates an even better match. Figure 8 shows PV output against overall system load and pool price, again showing good potential contributions. It is interesting to note that the energy value alone of the 1 kW PV array on 7 February would have had a spot market value of $8.92 and on 8 February a value of $22.44, or around $31 for the 2 days. This compares with a net metered value currently provided to the PV system owner of $1.60 in Adelaide (it would be less in Sydney).

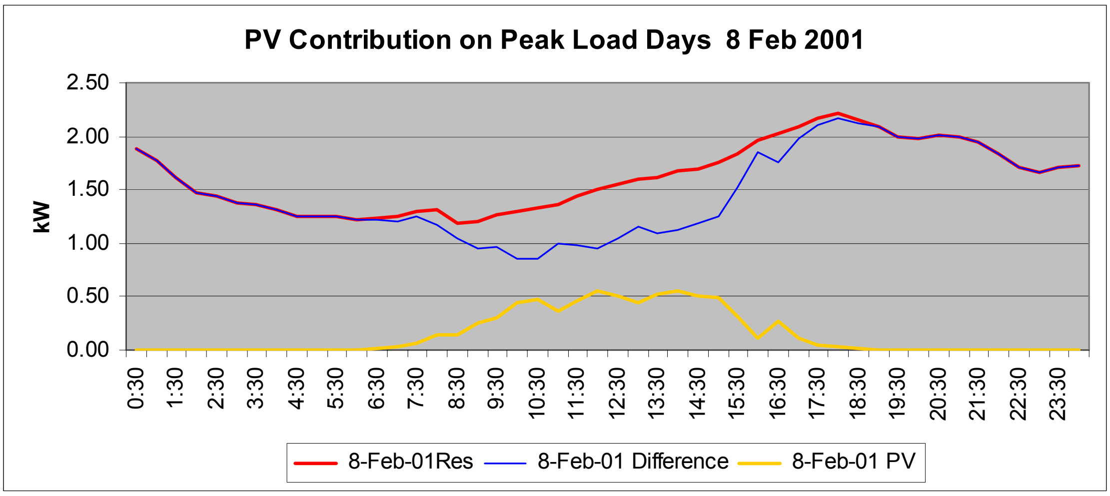

Figure 6: Typical Adelaide Residential Load against PV Output on a Peak Summer Day. (Source: Oliphant 2003)

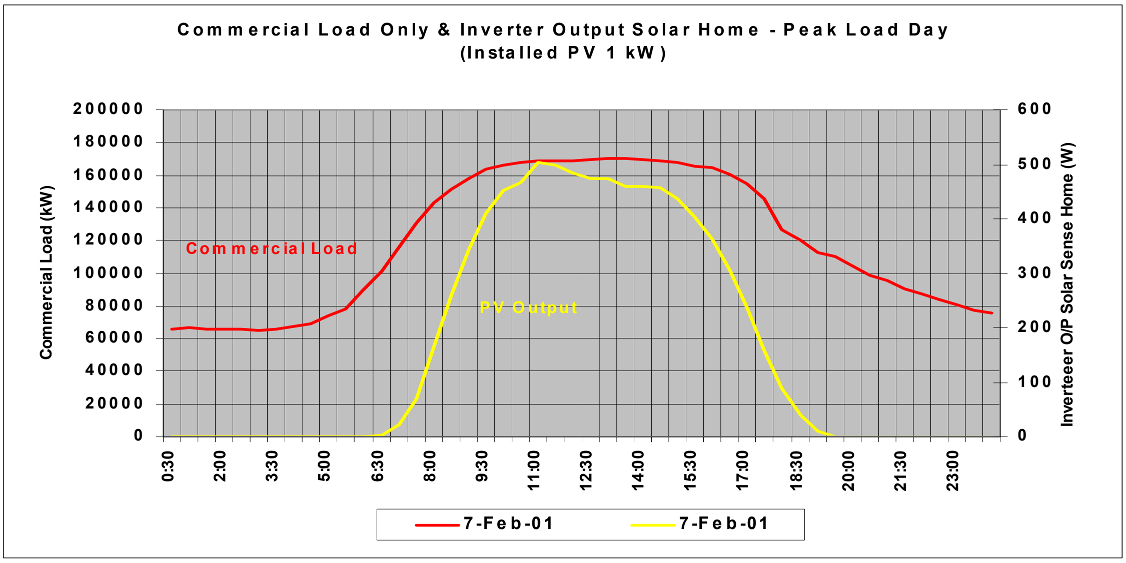

Figure 7: Typical Adelaide Commercial Load against PV Output on a Peak Summer Day. (Source: Oliphant 2003)

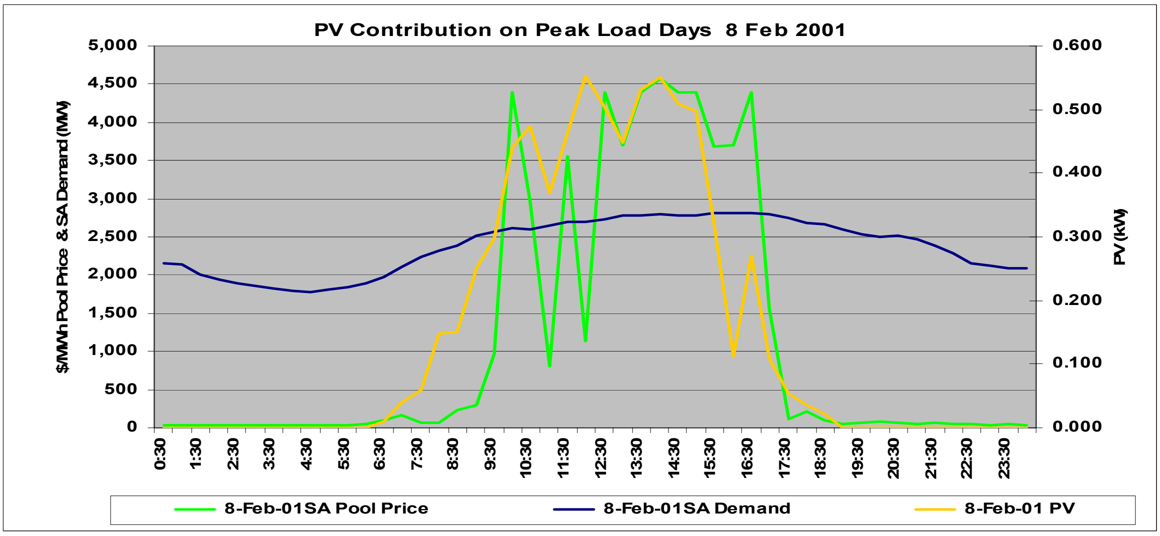

Figure 8: PV Output against Adelaide System Load and Pool Price on a Peak Summer Day. (Source: Oliphant 2003)

Because of the late residential peak periods in Western Sydney and Adelaide, the impact of changing the azimuth angle of the PV array from due North to due West was examined. Figure 9 shows the modelled results for an average (not peak) Sydney January day, changing both tilt angle and direction. It illustrates that the maximum PV output can be moved by 3 to 4 hours, although the drop-off in output becomes more rapid.

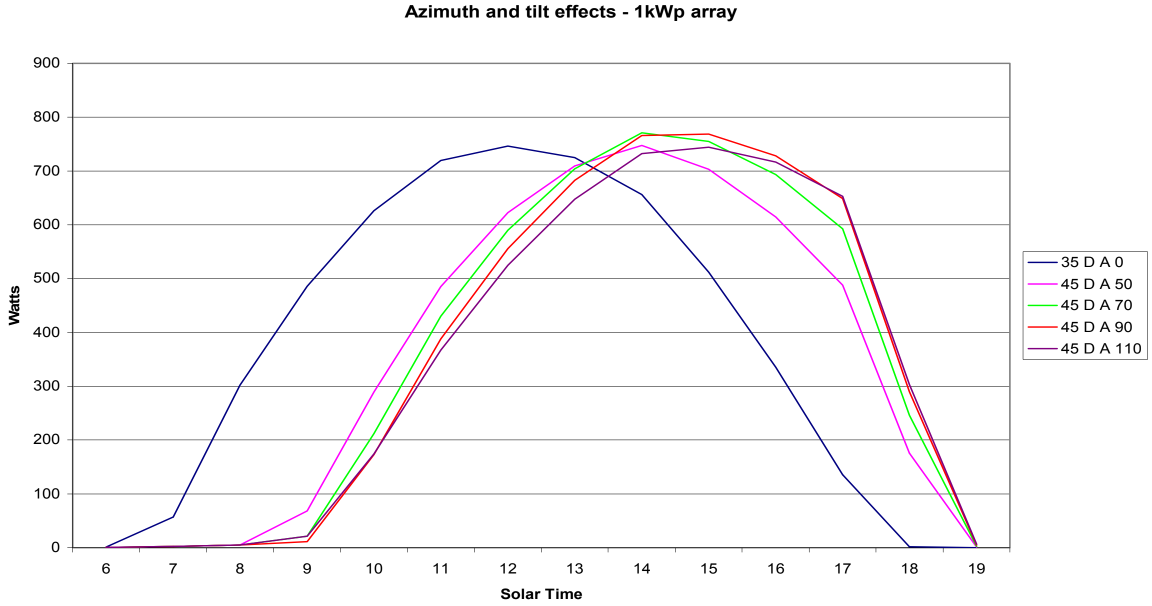

Figure 9: January Output from a 1 kW array in Sydney, with different Azimuth and tilt angles. (Source: Collins, 2003)

Figure 10 shows the output from a modelled 30 MW West facing PV array at 45 degree tilt superimposed on a load curve during a peak summer day from a substation at Bonnyrigg in Western Sydney. This substation has mixed commercial and residential load and shows a reasonable match to PV output. For the summer season, the daily PV energy output is not much affected by changing array orientation. However, earlier studies (Watt et al, 1998) have shown a decrease in annual energy output of around 20% for a West facing array in Sydney compared with a North facing one, as shown in Figure 11. Note also in Figure 11 the impact of cloud and haze on PV output in Sydney during February. Obviously the decision to place a PV array on a West rather than a North face would require the system owner being offered a summer loading on PV payback price.

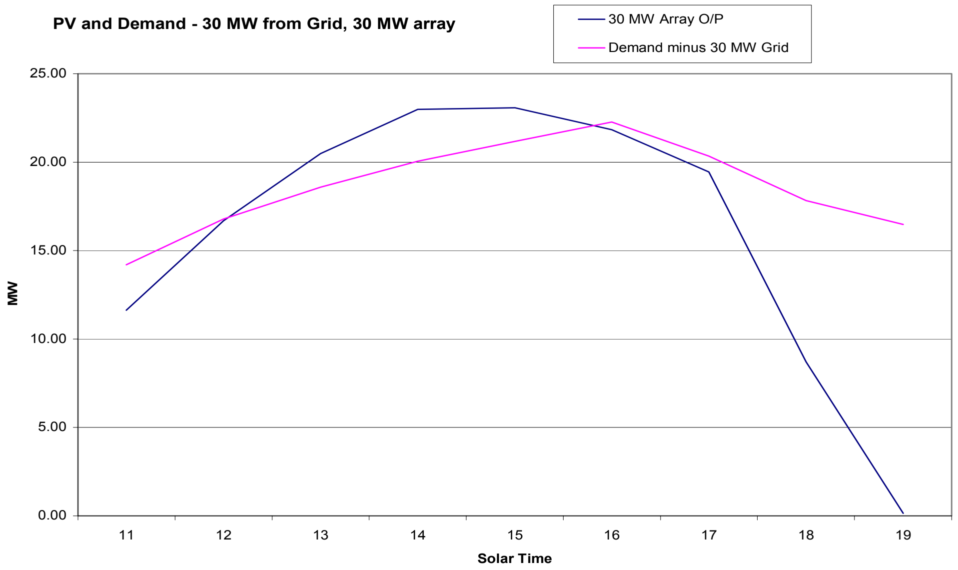

Figure 10: PV Output vs Feeder Load, Bonnyrigg, Western Sydney (Source: Collins, 2003 with Bonnyrigg load data from Integral Energy)

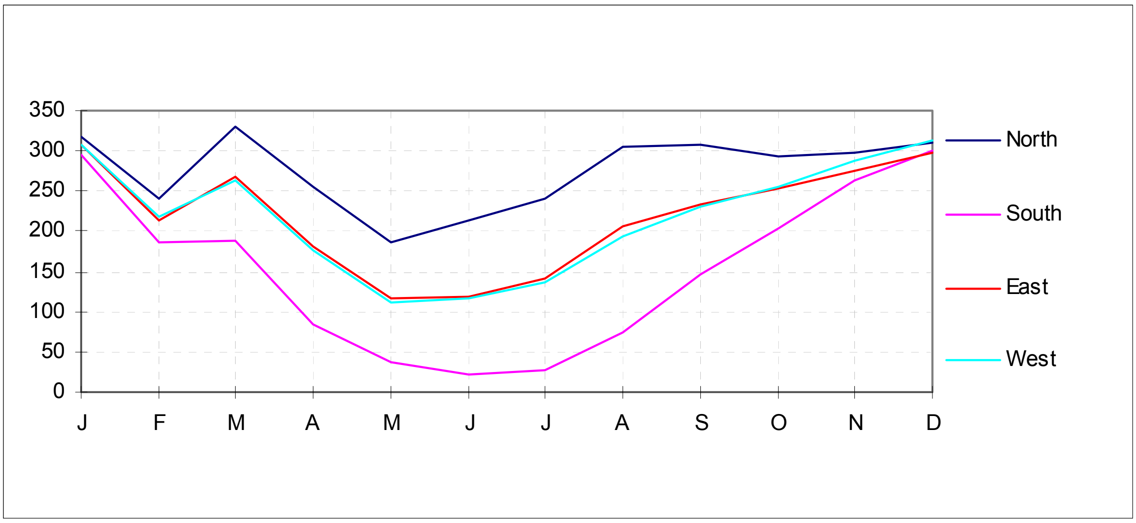

Figure 11: Annual PV Output in Sydney in kWh per Month for a 2 kW array at 25 degree tilt by Orientation, modeled on 10 year average weather data. (Source: Watt et al, 1998).

7. CONCLUSIONS AND FURTHER WORK

Analyses of PV output against system and feeder loads in Adelaide and Sydney indicate that PV can provide both energy and reliable network benefits to alleviate summer peaking problems and defer network upgrades. Detailed studies undertaken in the US provide evidence that such network benefits are predictable and significant. While PV output provides a good match to overall system load in Adelaide and Sydney, for individual feeders, output most closely matches those with a balanced or largely commercial load, rather than a residential load. For feeders with a predominantly residential load, west facing PV arrays could be considered, provided system owners can be compensated for reduced annual output. Also, crystalline silicon PV arrays should be kept as cool as possible on hot days to maximize output. The cost effectiveness of PV systems could be greatly enhanced were the network benefits accruing to electricity utilities taken into account. Excluding energy savings, even a year’s deferral of a feeder upgrade costing $1.5 million could result in savings of $80,000, while a year’s deferral of a substation upgrade costing $8 million would save $400,000 (Integral Energy, 2003). Already there is evidence that the higher electricity tariffs in Adelaide, combined with summer surcharges, may have increased consumer interest in PV. The AGO statistics on grid connected PV sales under the PV Rebate Scheme indicate that South Australia now has the highest uptake (AGO, 2003).

With summer peaking now a major issue for many electricity distributors, it would be useful to monitor existing PV systems in the areas of concern, to install and monitor systems sized and oriented for maximum peak load value and to begin to develop a range of mechanisms to encourage demand side solutions. For instance, it would be appropriate for the electricity industry to examine the cost effectiveness of incentives for tree planting, external window shading, insulation, energy efficient appliances and PV systems, as well as time of use metering and other initiatives which could be used to encourage a reduction in peak demand. None of these options has so far been tried and the residential sector is oblivious of the problems being caused by electricity use in peak periods.

8. DATA SOURCES AND ACKNOWLEDGEMENTS

For the NSW analyses, the solar simulation program used is UNSW BIPV Sim. Solar and temperature data is from the Australian Solar Radiation Data Handbook and was supplied with BIPV Sim.

Electrical Demand data for Western Sydney was supplied by Integral Energy.

Adelaide PV data is from the SolarSense house, New Haven, Adelaide, a joint project between the SA Housing Trust, ETSA Corporation, the Land Management Corporation and ERDC.

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