Analyses of Photovoltaic System Output, Temperature, Electricity Loads and National Electricity Market Prices – Summer 2003-04

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1. INTRODUCTION

Recent summer peaks in South Australia, Victoria and New South Wales have resulted in supply disruptions and, on some occasions, extremely high spot prices on the National Electricity Market (NEM). These events are now driving significant levels of investment in new generating plant, including peaking plant and in new or upgraded transmission and distribution network capacity across Australia. State governments are beginning to consider means of encouraging demand-side responses which might defer or eliminate the need for some of the planned network expansion. However, the supply focus of the NEM and retail electricity regulation makes if difficult to implement effective demand solutions. In addition, the political preference for maintaining uniform tariffs and reluctance on the part of the electricity industry to move towards electronic or time of day metering, eliminates the option of tariff signals in many areas. The analyses reported in this paper are aimed at assessing the effectiveness of PV in reducing summer peak loads on the electricity networks in South Australia, Victoria and New South Wales.

In previous work [1] the authors undertook a preliminary assessment of PV output from a small number of systems during the summer peak load periods in South Australia and New South Wales. This paper reports on more extensive analyses undertaken over the past summer, with data collected from 15 PV systems in 3 States and corresponding load data from 15 substations, as well as State level load and spot price data from the NEM.

2. BACKGROUND

Electricity demand has grown rapidly in Australia over the past decade and has been accompanied by an exacerbation of the "peakiness" of electricity demand patterns with increased air conditioning load considered to be the major cause. The latter is highly correlated with temperature extremes [1], [2] as is clearly illustrated in Figures 1 and 2. Additional diesel generation capacity is being installed in several States to cater for the coming summer's peaks.

PV can make a useful contribution to summer electricity loads, although the value to electricity networks and electricity retailers is dependent on actual feeder load patterns and on bulk electricity prices. PV output over the peak load weeks of summer 2003-04 corresponded well to system load at regional nodes for Victoria, South Australia and New South Wales, although load laged PV output slightly on some days. Similarly, PV output corresponded well with NEM price over peak load weeks for all three States. At feeder level, PV output correlates well with loads on feeders with a high proportion of commercial load, indicating a strong case for PV use in commercial buildings in Australia. For residential loads, the peak is typically in mid to late afternoon. In areas with high air conditioner penetration, the peak load is significantly higher on hot days and can remain high up to 6 or 7pm. For PV to contribute usefully to the peak, the PV output curve must be displaced or storage added. This may be in the form of electrical or thermal storage.

This report looks in detail at the potential for PV to contribute to summer electricity loads during the high demand week, 9 – 15 February 2004. This week was chosen because peak loads for summer 2003-04 occurred on Saturday 14 February in SA and Victoria. In NSW, the peak day was Tuesday 9 March, with a corresponding peak price of $9,702/MWh. However, NSW also experienced high loads and prices in the chosen week with the maximum demand occurring on Tuesday 10 February.

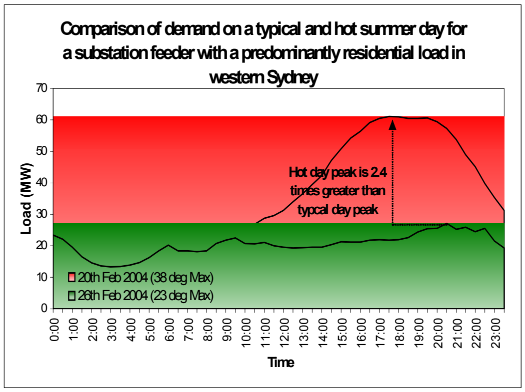


Figure 1: Residential load on a Western Sydney feeder on a typical and a high temperature summer day.

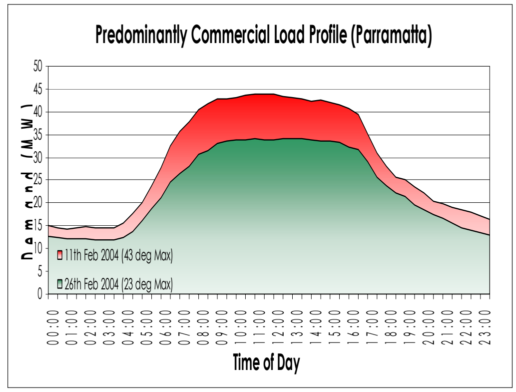


Figure 2: Commercial load on a Western Sydney feeder on a typical and a high temperature summer day.

3. SUMMARY OF FINDINGS

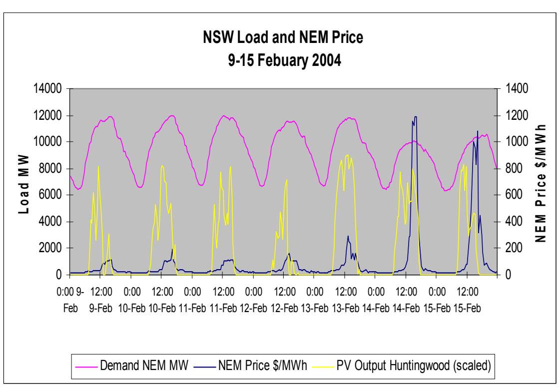
3.1 NEM demand and Regional Reference Price (RRP)

For most of 2003-04 the regional reference prices (RRP) on the NEM have been around $25-35/MWh [6]. In February the averages were much higher, and for the hot week 9 – 15 February, even higher still. Averages are calculated over a whole day. If calculations are made over the period 7am – 10pm, which is frequently referred to by electricity retailers as the "peak period", averages were higher still. See Table below. It can therefore be seen that potential benefits could arise for retailers having PV on the network, especially during the hot weeks.

Table 1: Peak Period Electricity Prices 2003-04

State	Ave Peak RRP February $/MWh	Ave Peak RRP 9 –15 Feb $/MWh	Some Peak prices for February $/MWh
NSW	$48.72 ($116.44 Mar Ave)	$116.19	$1198, 14/02 $2521, 21/02 $9702, 9/03 (NSW Peak day)
SA	$108.35	$252.38	$4750, 13/02 $3039, 14/02
Victoria	$48.30	$102.79	$1096, 14/02 $1608, 20/2

To find out how well NEM load, RRP and PV matched each other during 9 – 15 February, Figures 3 – 5 were plotted. Also a plot of the March peak load week for NSW is given which, as can be seen, does not have the sustained high demand as the one in February.



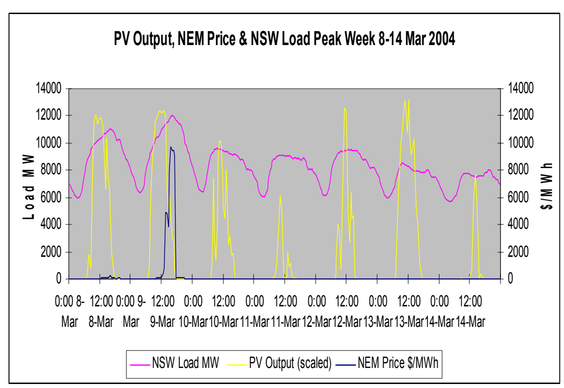


Figure 3: NSW Load, NEM Price & PV Output for the Weeks of Peak Load in Summer 2004[1].

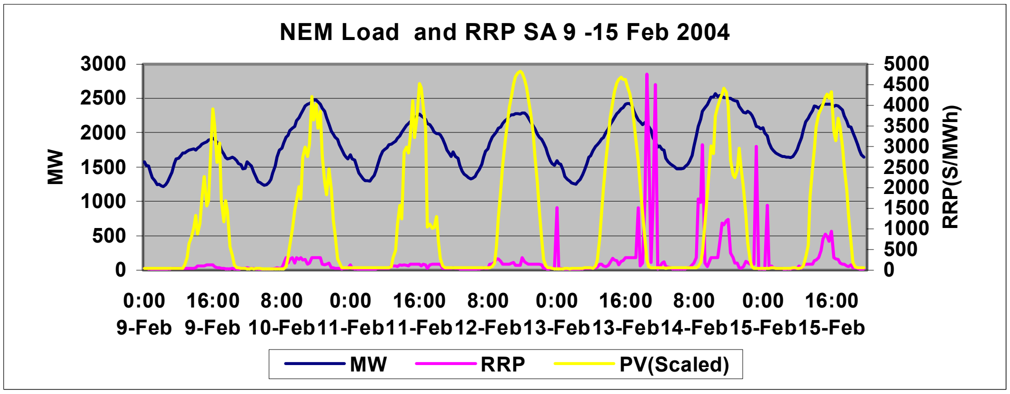


Figure 4: South Australian Load, NEM Price & PV output for the Week of Peak Load Summer 2004.

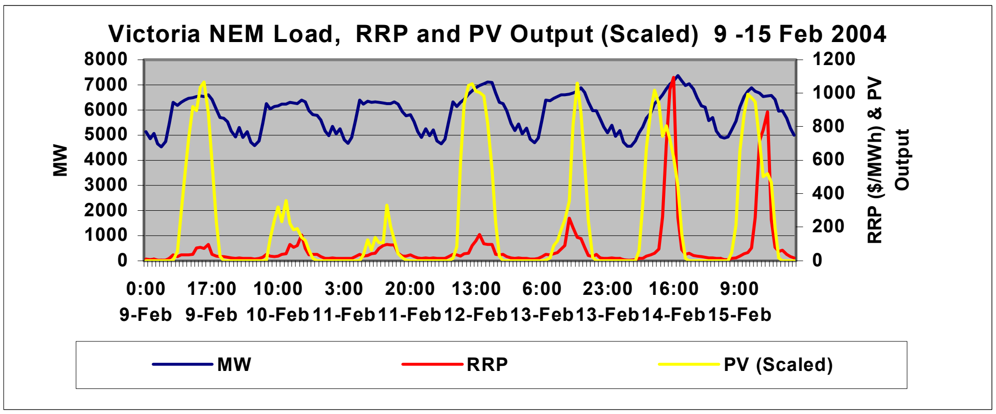


Figure 5: Victorian Load, NEM Price& PV output for the Week of Peak Demand Summer 2004

Better correlation between high RRP and peak daily load occurred in NSW and Victoria than in SA, where the latter experienced high prices during off peak periods on a few occasions. This may be fortuitous or due to the combined effect of high overnight air conditioning load and off peak water heating causing network problems. The PV load match, however, appears to be best in SA and NSW with cloud cover over the Queen Victoria Market, (QVM), reducing the impact of this system in Victoria during the peak load week. (The impact of PV on demand will be discussed further in section 3.4)

Note: In SA and Victoria the NEM system demand peak is on a Saturday, 14 February, with the Sunday peak being not far behind, an unusual occurrence but probably a forerunner of things to come as the contribution of residential air conditioning to peak demand becomes increasingly large.

3.2 NEM load and selected substation, commercial and residential loads

In NSW demand data was available from a residential and commercial substation in Western Sydney, an industrial substation in Sydney and a country substation. In SA data from a residential transformer having ~ 100 customers was provided and there was no data from Victoria besides that from QVM and the NEM. The relationships between these loads are shown in Figures 6.

In NSW it can be seen that the commercial and industrial loads declined significantly over the weekend, as would be expected, whereas in Western Sydney residential demand increased significantly, although the overall State demand shows a more typical weekend pattern. The load on 15 February was higher on the Western Sydney residential feeder than on 14 February, as was the temperature (37 C rather than 34 C). On both days NEM demand was higher than on the weekend of peak load week 8 –14 March (Figure 3) probably because of a higher residential air conditioning load.

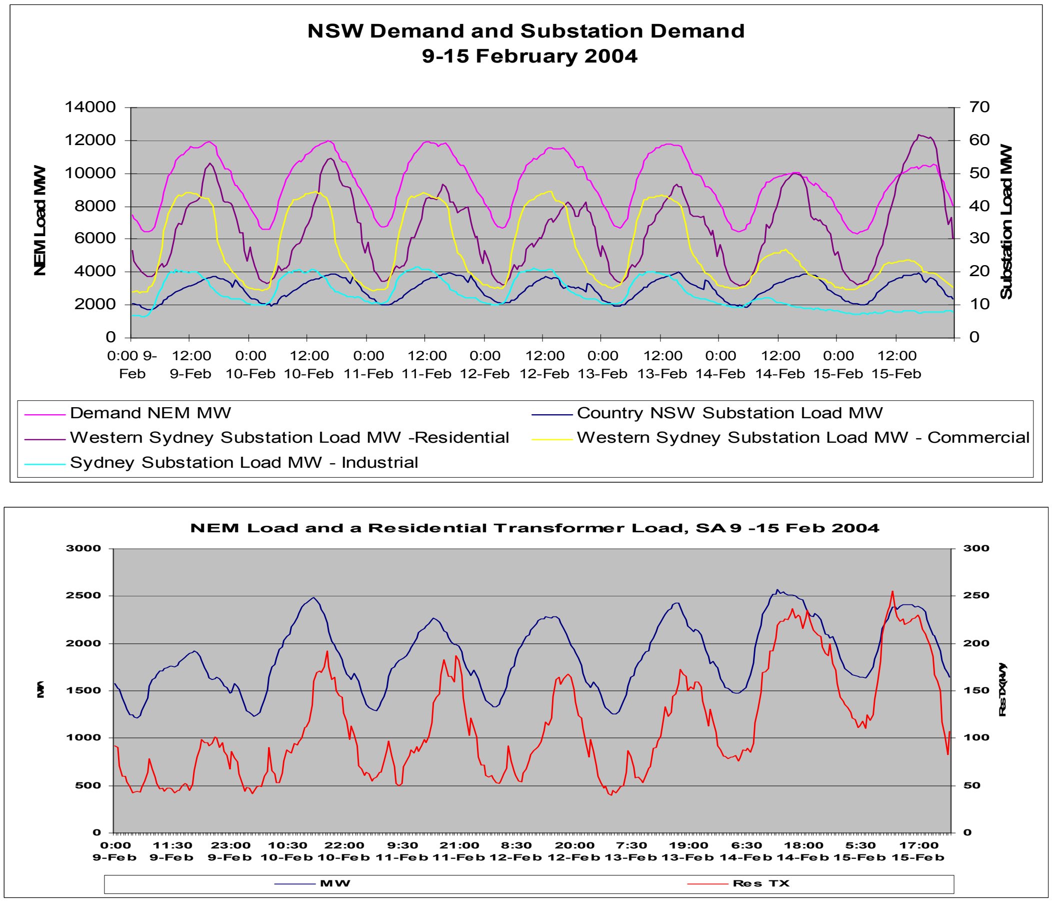


Figure 6: NSW and SA System Load and Feeder Loads for the Week 9-15 February 2004.

In SA, as mentioned previously, the NEM system demand peak was on Saturday 14 February, with the Sunday load being not far behind. It is interesting to note that the peak on the residential transformer in SA increased by 2.5 times between 9 and 15 February. The strong correlation between temperature & residential load is shown for NSW and SA in Figures 7 and 8.

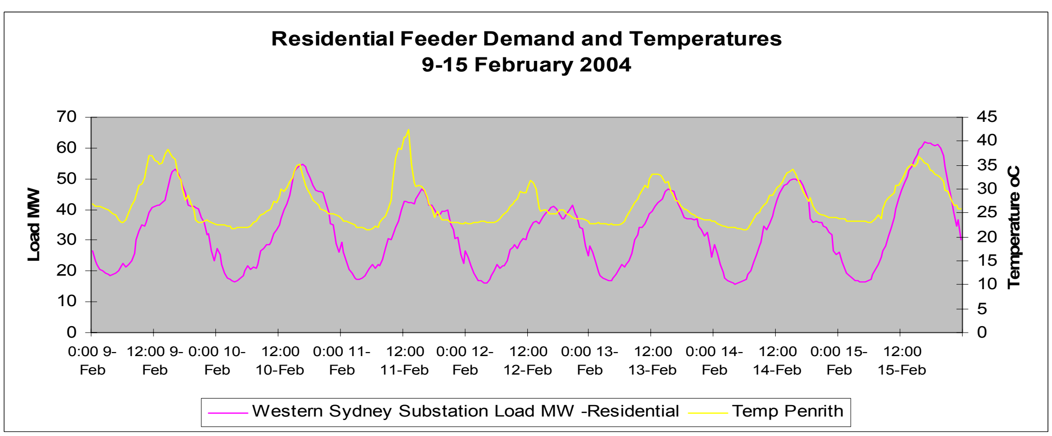


Figure 7: Substation Loads and Temperature 9-15 February 2004 - NSW.

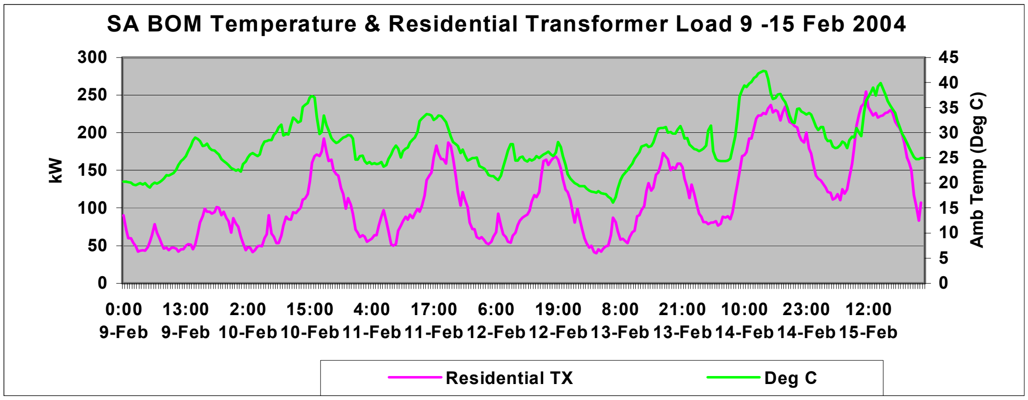


Figure 8: Residential Transformer Loads and Temperature 9-15 February 2004 - SA.

3.2 PV OUTPUT AND TEMPERATURE

The performance of crystalline silicon arrays can decline with high temperatures, especially for rooftop systems where ventilation is limited and array temperatures can be 30 to 40 degrees higher than ambient. Also, hot days can be characterised by haze or storm clouds whilst few PV systems installed on buildings are optimised for peak summer output. Nevertheless, the results from 15 systems monitored over the past summer indicate that, although impacted by temperature, PV output on summer days remains significant, as illustrated in Figure 9.

A brief attempt was made to quantify the effect of temperature on output using the data from one PV array in SA. To observe the effect more readily, data from the whole of February was used and 9 quite cloudy days removed. Also, as PV output changes with time of day, just 2 times of the day were looked at - 13:00 EST, when system demand and PV output are near peak, and 19:00 EST when demand starts to decline and PV output is getting low. Results are shown in Figure 10. Though the R^2 fit of the trend lines are not very good, a definite decline of ~ 6 % in PV output can be seen over an ambient temperature range of about 25 C - 36 C for this particular mono crystalline array. Results should be regarded as preliminary and will be repeated for different PV types and mounting systems. A preliminary assesment of the other PV systems used for this study shows a 2-6% reduction in PV output on February days when the temperature exceeded 30 degrees, compared with lower temperature days.

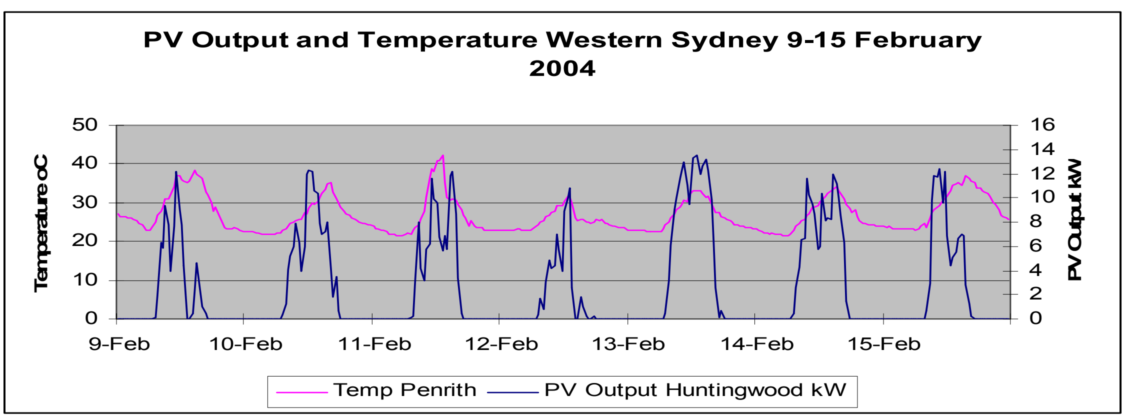


Figure 9a: PV output and temperature over a peak load week - Western Sydney.

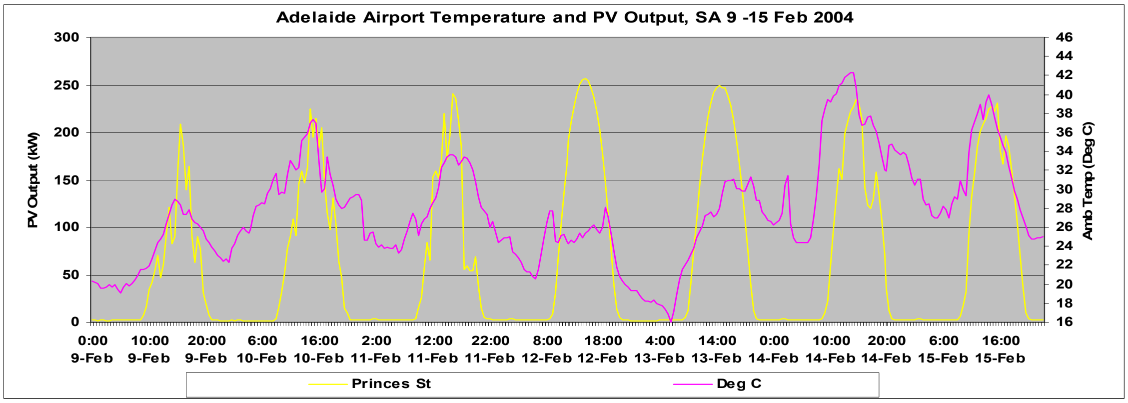


Figure 9b: PV output and ambient temperature over a peak load week – Adelaide

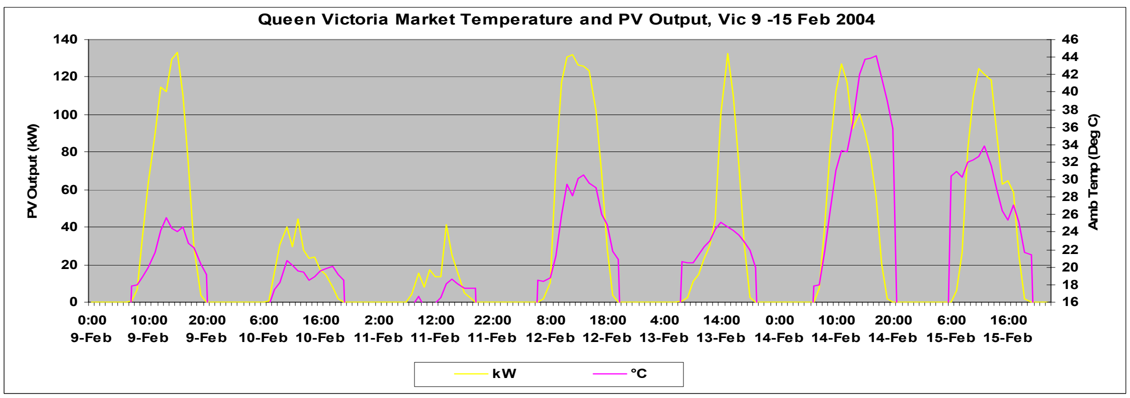


Figure 9c: PV output and ambient temperature over a peak load week - Melbourne

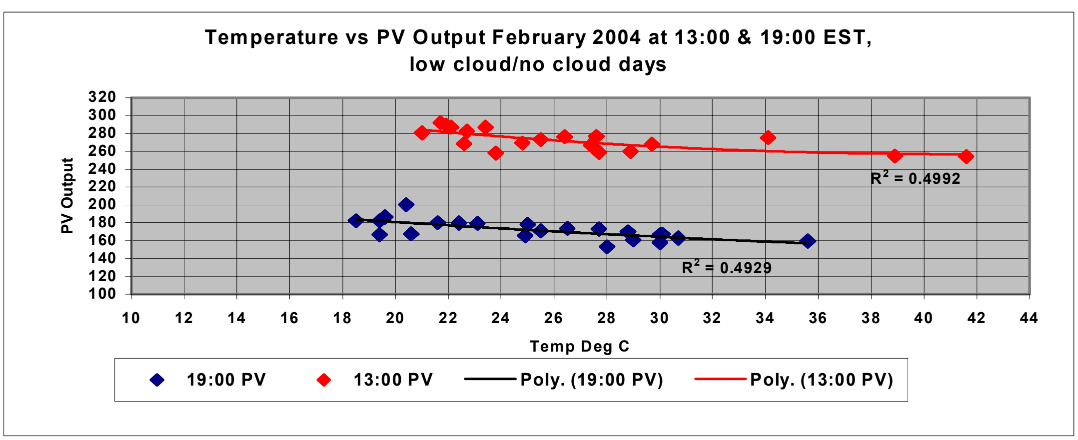


Figure 10: PV array output vs temperature at 13:00 & 19:00 EST in SA, February 2004.

3.4 POTENTIAL PV IMPACT ON LOAD

For summer peaking feeders, the shape of the load curve determines the potential for PV to defer network upgrades. For feeders with high residential loads which peak in the late afternoon, PV can reduce load prior to the peak event, thereby potentially reducing transformer heating, however its contribution to the peak load itself is low. Figure 11 shows the load and the load reduced by an appropriately sized PV array for feeders with predominantly residential loads in NSW.

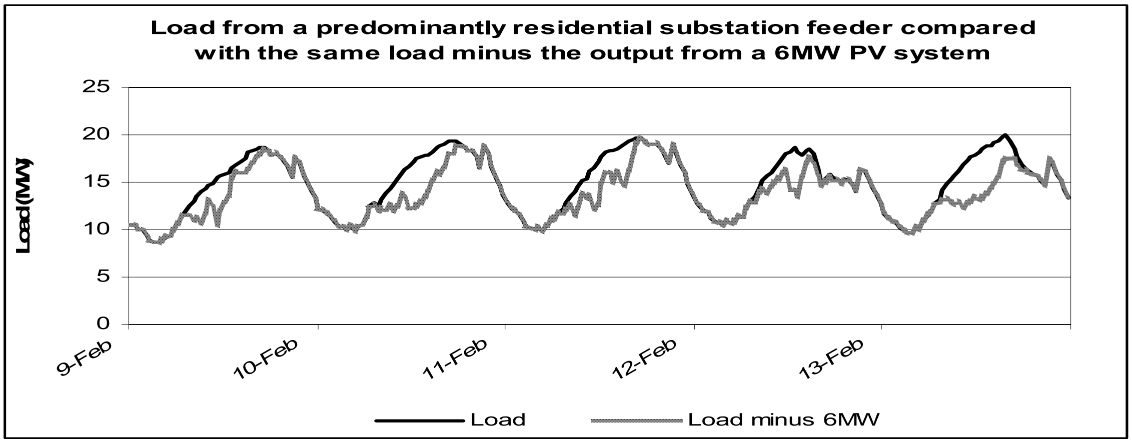


Figure 11: Potential PV contribution to NSW residential load during peak demand.

For feeders with a mixed load, including commercial and industrial, and for the overall system load, the PV contribution can be more useful. Figure 12 shows the impact PV could have on a commercial feeder load in Western Sydney.

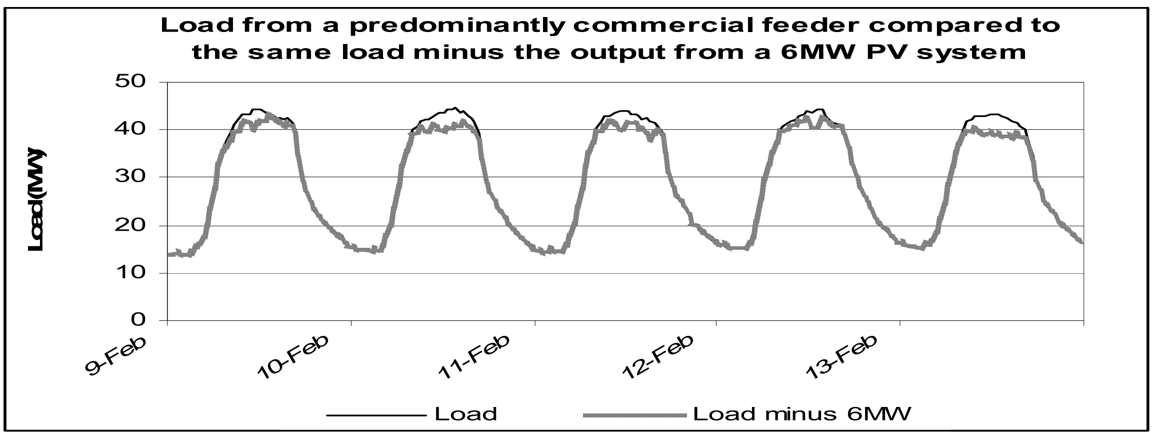


Figure 12: Potential PV contribution to NSW commercial load during periods of peak demand.

In SA the match between PV output and demand on a residential suburban transformer with around 100 homes on it and with SA system load was better than expected, as shown in Figures 13 & 14. More work will need to be done to see if these results are reproducible elsewhere.

In Victoria, days of cloud during the peak load week reduced the impact of PV at the Queen Victoria Market, as shown in Figure 15. Looking at the PV output in all three States during this peak week highlights the advantage of distributed installations of PV which can smooth the PV output across a region to cater for transient cloud cover. .

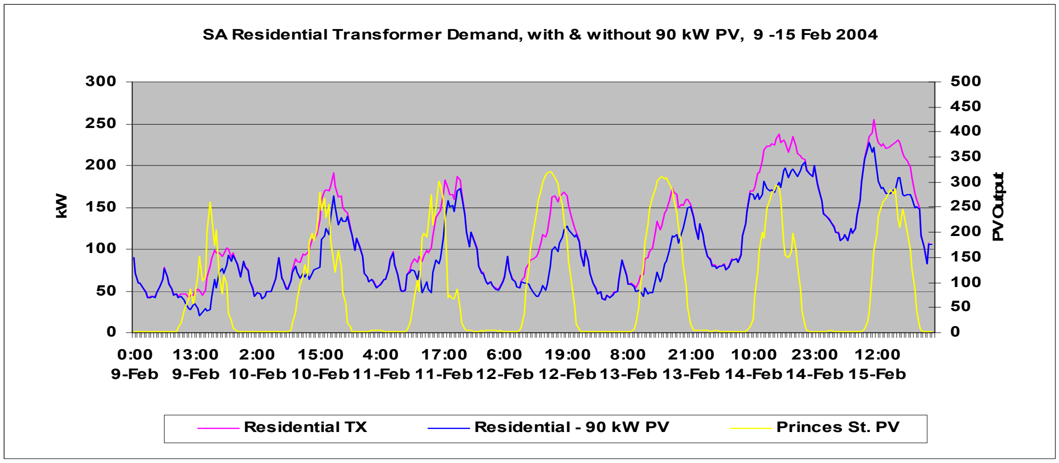


Figure 13: Potential PV contribution to SA residential load during periods of peak demand.

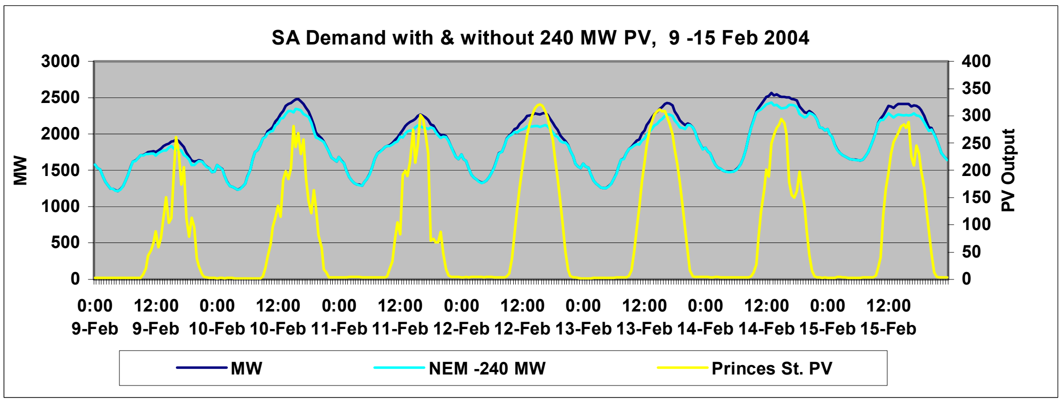


Figure 14: Potential PV contribution to system load during during periods of peak demand

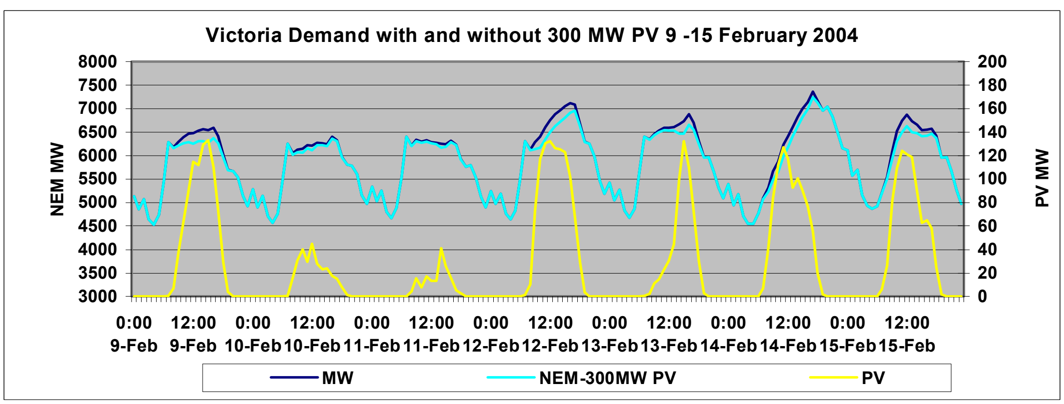


Figure 15: Potential PV contribution to Victorian system load during periods of peak demand

3.4 ASSESSING NETWORK VALUE

There are several ways of assessing the network value of PV. One is to compare the long term pattern of PV output with the pattern of electricity demand. In Figure 16 the chronological pattern of a commercial load has been re-ordered as a load duration curve, maintaining the correspondence between PV output and demand. In Figure 17 the load duration curve is shown along with load minus the coresponding PV output. Again, PV output is more concentrated at the higher load points on the commercial feeder, whilst PV output on the residential feeder is spread across a wider range of loads.

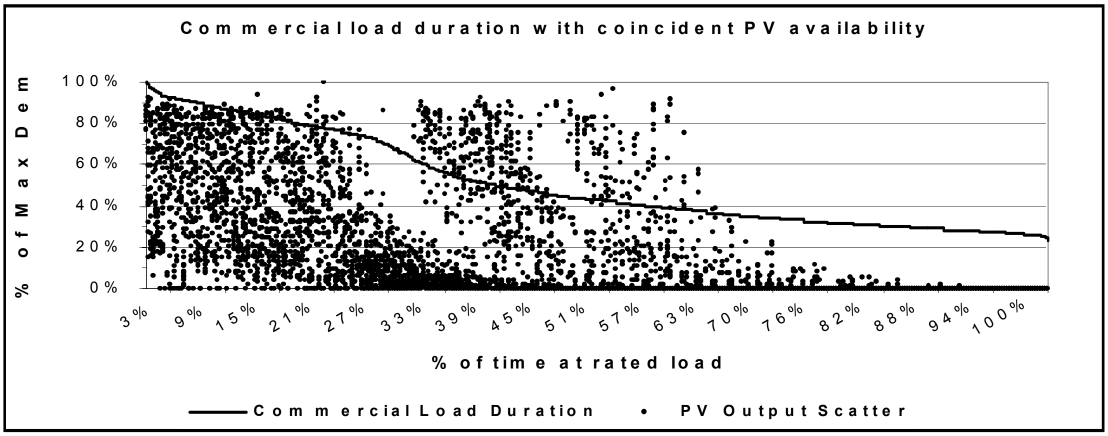


Figure 16: Normalised load duration curve for a commercial feeder in Western Sydney with coincident PV output - Summer 2003-04.

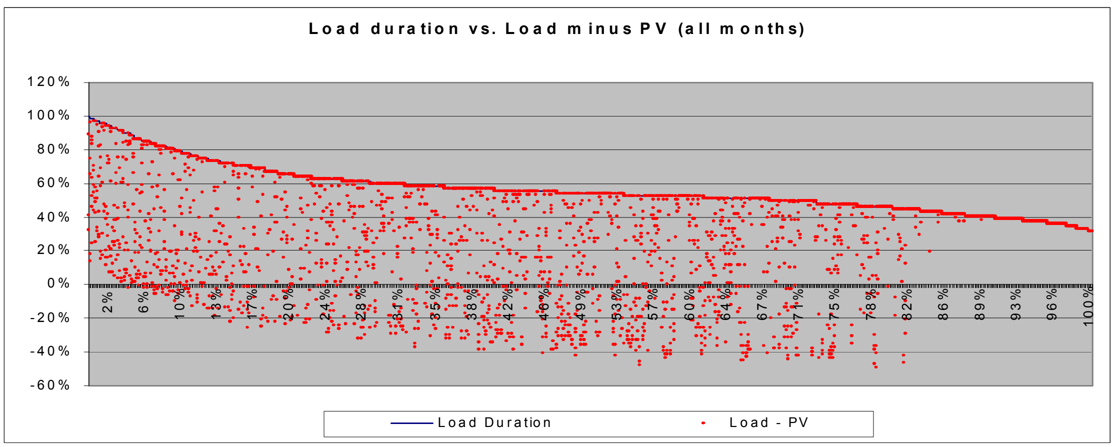


Figure 17: Normalised load duration curve for a NSW country town feeder showing the potential load reduction due to coincident PV output - Summer 2004.

As for the analysis undertaken in Section 3.2, where the relationship between PV output and temperature was examined, an attempt was made to quantify the impact of PV on a residential transformer. Once again 9 cloudy days were removed and data for the month of February used at 2 particular times of the day, 13:00 EST and 19:00 EST. The results are shown in Figure 18.

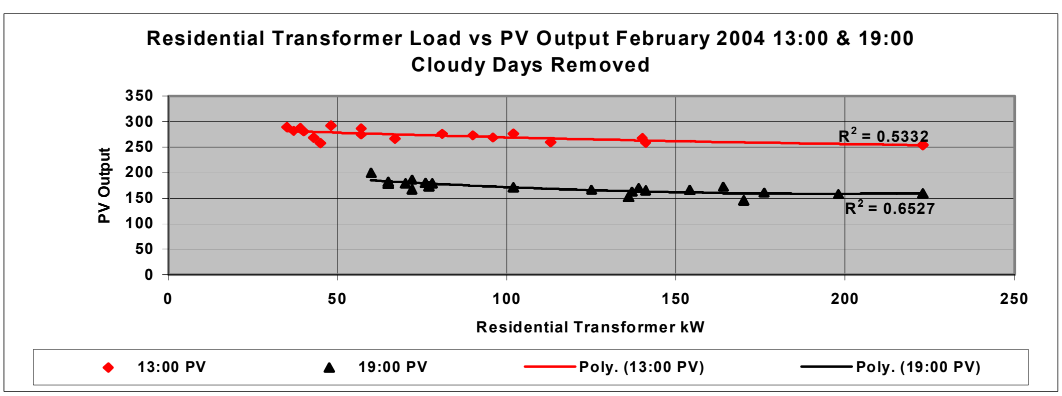


Figure 18: Residential TX Load vs PV Output 13:00 and 19:00 EST on low/no cloud days Feb 2004

Though the R^2 fit to the graphs is again not very high, a definite trend is seen between Residential Load and PV output on the low/no cloud days. High residential loads, which occur on high temperature days, correspond to about a 10 % drop in PV output compared with the low load days. Additionally the decline in output between 13:00 and 19:00 on the hottest day was ~ 35 %. The conclusions drawn are that on low /no cloud days the output of this particular PV system in SA would decline by about 10 % on hot days compared with mild days and contribution to the network at 19:00 EST would be ~35 % less than at 13:00 EST. Similar analyses will be conducted in future using data from the various sites to see whether this methodology is useful in estimating the range of PV contributions to residential loads at different times of day. An assessment of the retail value of PV was discussed in Section 3.1.

4. DISCUSSION AND CONCLUSIONS

PV can make a useful contribution to summer electricity loads, although the value to electricity networks and electricity retailers is dependent on actual feeder load patterns and on bulk electricity prices. PV output over the peak load weeks of last summer corresponded well to system load at regional nodes for Victoria, South Australia and New South Wales, although load lags PV output slightly on some days. PV output typically peaks prior to the peak NEM price over peak load weeks for all three States. However, analyses are needed at specific feeder level in order to assess the PV value over summer. For instance, PV output correlates well with loads on feeders with a high proportion of commercial load, indictating a strong case for PV use in commercial buildings in Australia. PV systems on schools (which are the focus of many State based PV programs) also correlate well with daytime load profiles and, since schools in Australia are closed for 6 to 8 weeks over summer, PV output could contribute usefully to other loads during this summer peak load period.

For residential loads, the peak is typically in mid to late afternoon. In areas with high air conditioner penetration, the peak load is significantly higher on hot days and can remain high up to 6 or 7pm. For PV to contribute usefully to the peak, the PV output curve must be displaced or storage added. Earlier studies [1, 5] have also shown that west facing arrays, with higher tilt angles would allow the PV load curve to be shifted towards the afternoon. A key requirement also is the need for improved residential building energy performance, so that overall cooling needs can be reduced.

PV installations provide a year round source of day-time electricity. Their value for peak load reduction is dependent on the load pattern of the individual feeders to which they are connected. Appropriately placed PV installations, along with moves to reduce electricity use and to better manage peak demand, may provide lower risk investments than network augmentation. The use of PV and other distributed generation options can also improve the resilience and security of the electricity system. Finally, in Australia PV use displaces fossil fuels and so has an important role to play in reducing greenhouse gas emissions.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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