Centre for Photovoltaics Engineering
UNSW

Photovoltaics and Peak Electricity Loads
Summer 2003-04

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Support and data provided by:
BP Solar, Origin Energy, SEAV

Data provided by:
Integral Energy, Country Energy

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1. Introduction

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 for the summer of 2003-04, 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 National Electricity Market (NEM). This work provides a basis for selecting sites where PV can provide a useful contribution to local load.

The study was undertaken by UNSW in a contract with the Business Council for Sustainable Energy, the latter on behalf of BP Solar, Origin Energy and the Sustainable Energy Authority of Victoria. Data for the analyses were provided by BP Solar, Origin, Country Energy, Integral Energy and ETSA Utilities.

1.1 Study Objectives and Methodology

The objective of the study was to correlate PV output from a range of sites against insolation, temperature, electricity load and NEM prices over the summer period.

Data collection:

- PV output data was collected from the sites listed below over the summer period(s).
- Radiation and temperature data was also collected or sourced from sites close to the PV sites over the summer period(s).
- Additional insolation and temperature data was sourced from the Bureau of Meteorology, or other sources, as necessary
- Substation load data was provided by Origin Energy, Integral Energy, Country Energy and other Network Service Providers as necessary for critical substations over the summer period(s).
- State level electricity price and load data was sourced from the National Electricity Market.

It should be noted that the PV data was collected from real PV sites, that is, orientation, array tilt and array placement have been dictated by site and building restrictions and are usually not optimal either for annual or for summer output. Hence the data presented should not be interpreted as reflecting module performance, although it could be used to make recommendations regarding system installation for maximum summer output.

1.2 PV Sites studied

Site	Control	Data collection
South Australia		
2 Housing Commission Homes	Monica Oliphant	Monica Oliphant
4 Homes	Origin Energy	Origin Energy
Art Gallery	Uni SA	Uni SA
SA Museum	Uni SA	Uni SA
Victoria		
Queen Victoria Markets	Origin Energy/BP	BP Solar
Country NSW		
Mudgee House	Muriel Watt	BP Solar
Queanbeyan	Country Energy	Country Energy
NSW		
Huntingwood and Coniston	Integral	Integral Energy
3 homes – Newington 1 home - Harbord	BP Solar	BP Solar

2. Background

2.1 Load growth and temperature correlation

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. The latter is highly correlated with temperature extremes [1], [2] as is clearly illustrated in Figures 1 and 2. In the rapidly growing region of Western Sydney, load estimates for new houses have been increased from 3.5 to 4 kVA peak to 6 – 7.5 kVA peak [2].

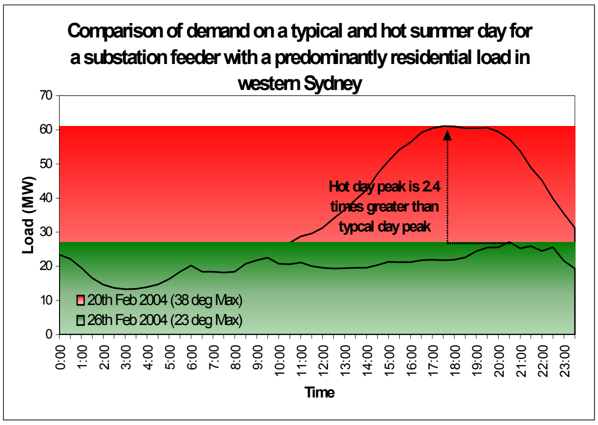


Figure 1: Residential load on a Western Sydney feeder on a typical and high temperature summer day.

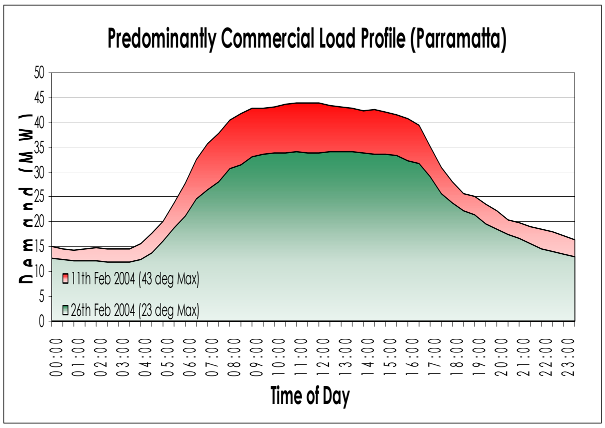
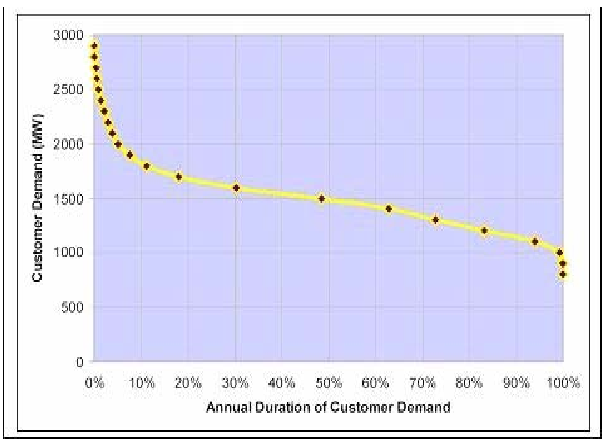


Figure 2: Commercial load on a Western Sydney feeder on a typical and high temperature summer day.

The summer peak has already, or is about to overtake the winter peak in most States and is compounded by the effective derating of network assets and gas turbine peaking plant when ambient temperatures are high. Additional diesel generation capacity is being installed in several States. System load duration curves are becoming "peakier", as shown in Figure 3, 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. Similarly in Western Sydney, the peak on hot days is 1000MW higher than the normal summer peak of 2500MW, while 383MW is used for only 25 hours a year [2].



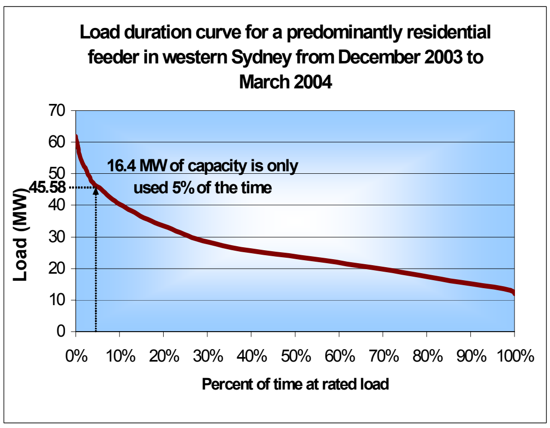


Figure 3: Load duration curves for South Australia and for a residential feeder in Western Sydney.

2.2 Electricity industry response

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. These events are now driving significant levels of investment in new generating plant, including peaking plant ($5 billion this decade) and in new or upgraded transmission and distribution network capacity ($8 billion this decade) across the country [3]. Several electricity distribution companies have already purchased additional diesel generators to cater for expected peak loads during the coming summer (2004-05).

One retailer in South Australia has already introduced a summer peak tariff which is 11% higher than the standard tariff. 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 [4]. However, the suppy focus of the National Electricity Market 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, now gradually changing, eliminates the option of tariff signals in many areas. The analyses undertaken for 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.

3. Summary of Findings

3.1 Characteristics of peak electricity load weeks

The peak loads for summer 2003-04 in SA and Victoria occurred on Saturday 14 February. For NSW, the peak day was Tuesday 9 March, although the week 9-15 February also experienced high loads, with the peak for NSW occurring on Tuesday 10 February. Most of our analyses were done for December to February, since March data was not then available.

On 14 February NEM prices were high: ~$3000/MWh in SA, ~$1100/MWh in Victoria and ~$1200 in NSW, though in SA RRP was even higher on 13 February, $4750/MWh at 21:00 and $4505 at 23:00. For NSW, the peak price of $9702/MWh occurred on 9 March. System loads and NEM prices are shown in Figures 4-6.

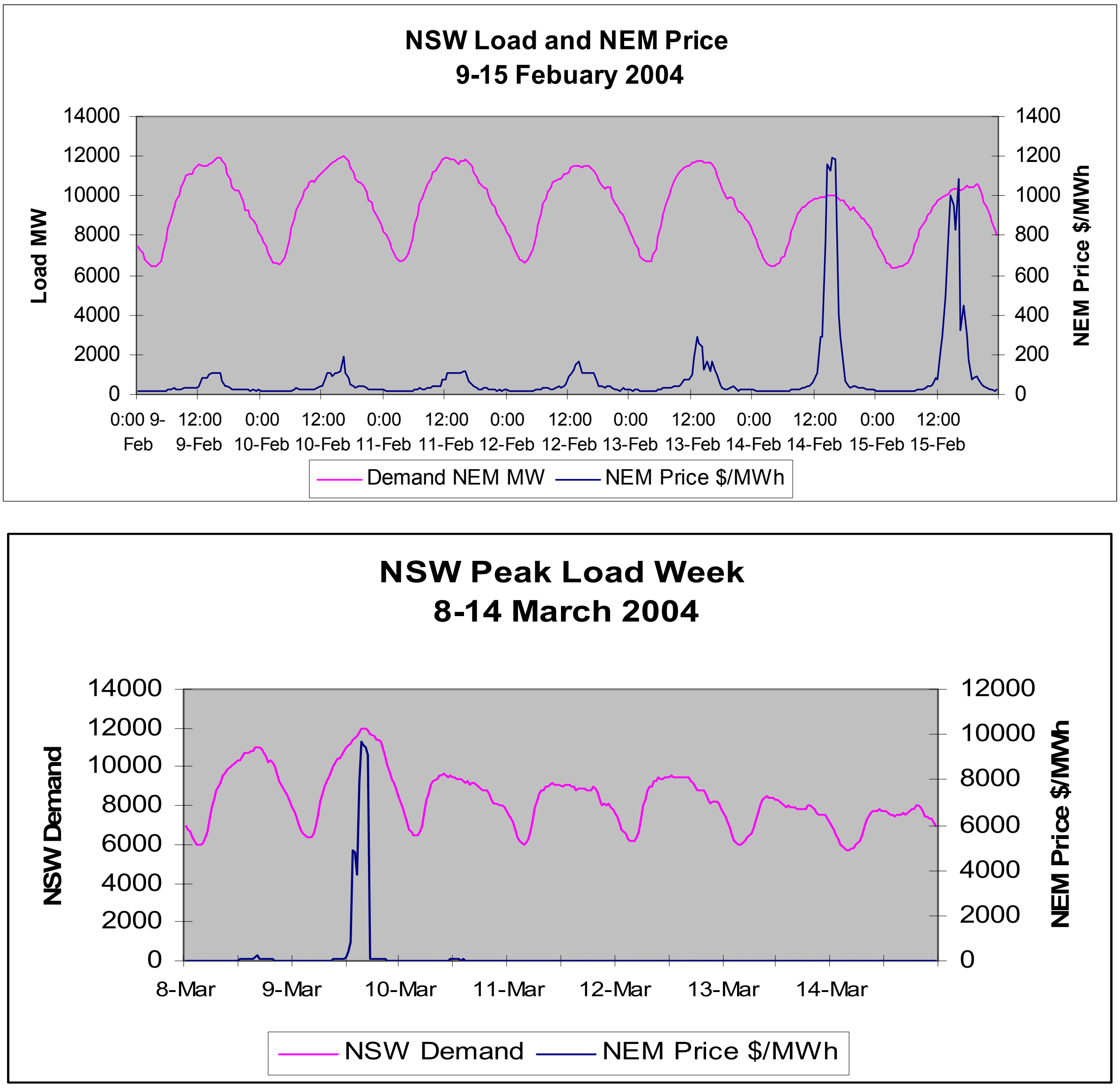


Figure 4: NSW Load and NEM Price for the Weeks of Peak Load in Summer 2004.

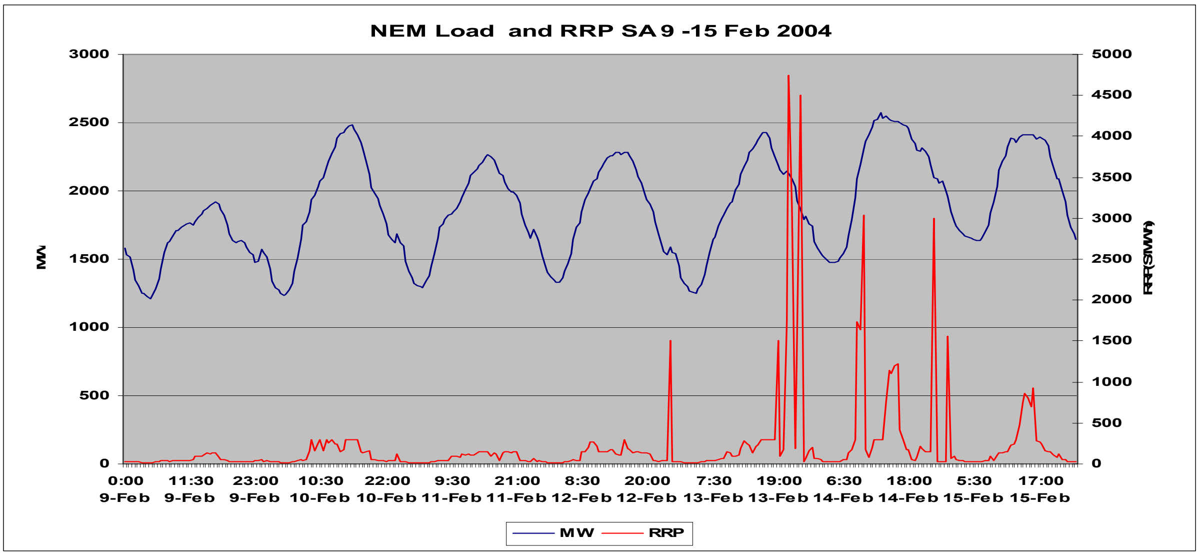


Figure 5: South Australian Load and NEM Price for the Week of Peak Load Summer 2004.

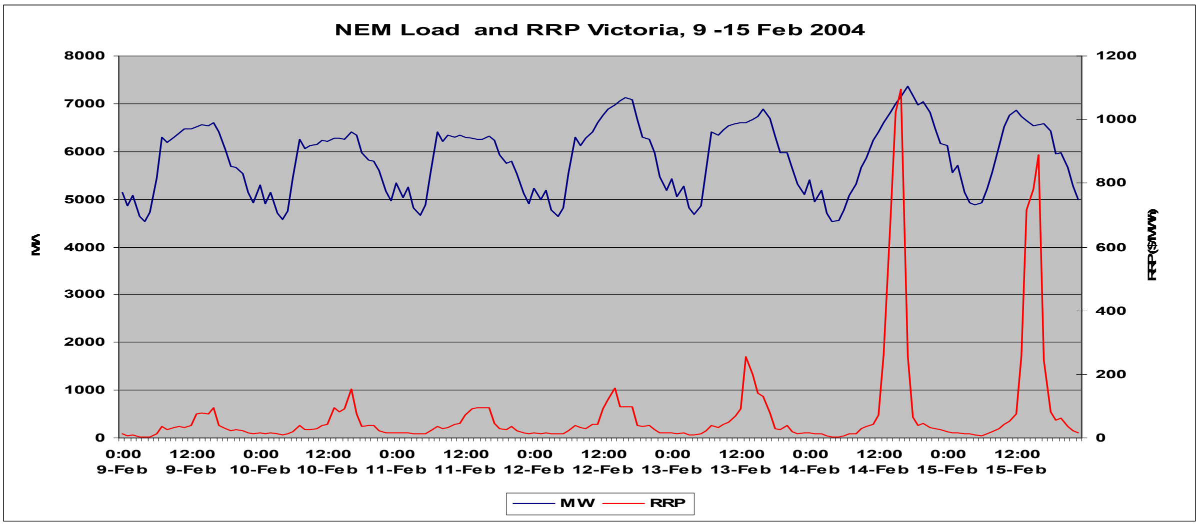
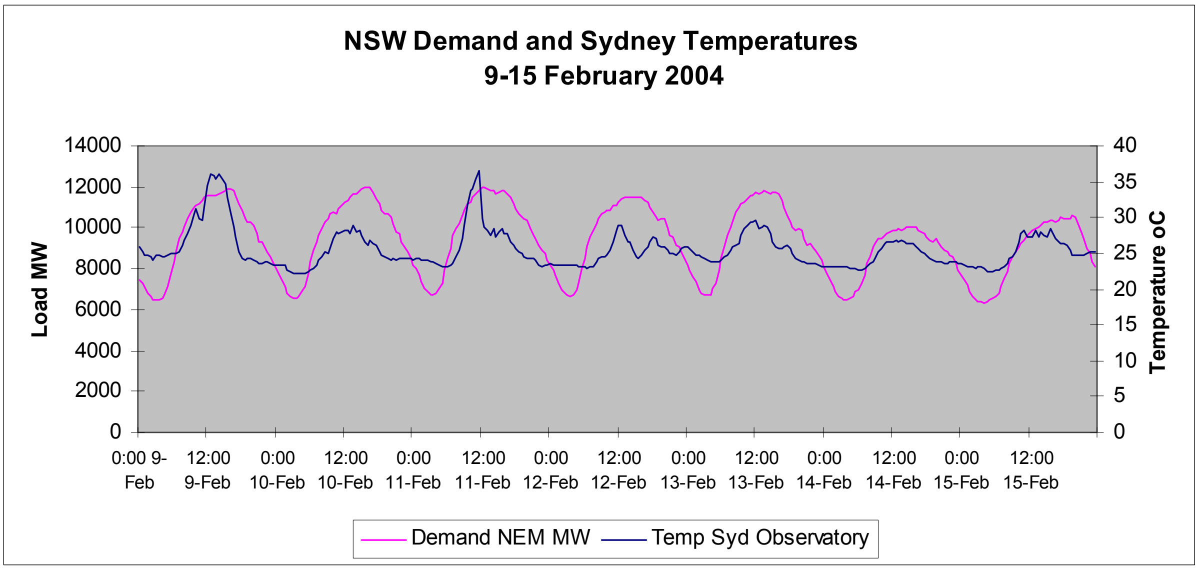
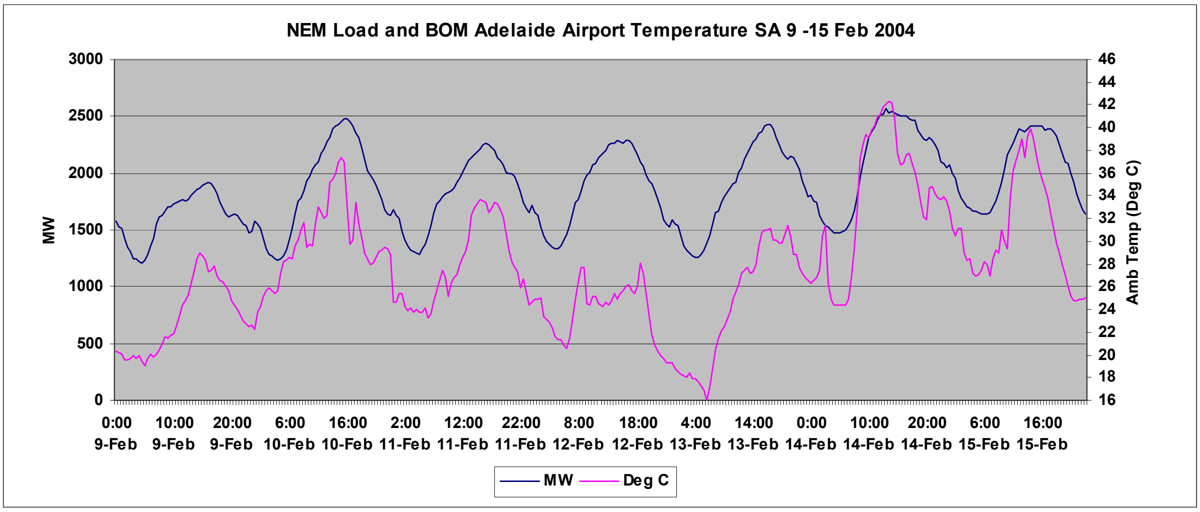


Figure 6: Victorian Load and NEM Price for the Week of Peak Demand Summer 2004

The maximum temperature on the peak load days was quite high: 35 C in NSW on 10 February; 43 C in SA and 44 C in Victoria on 14 February; and 39 C in NSW on 9 March. In both SA and Victoria, the maximum load on Sunday 15 February was down a little, ~ 4 %, though still very high for a weekend, indicating that residential air conditioners are now having a very large impact on maximum demand. System load and temperature are shown in Figure 7.





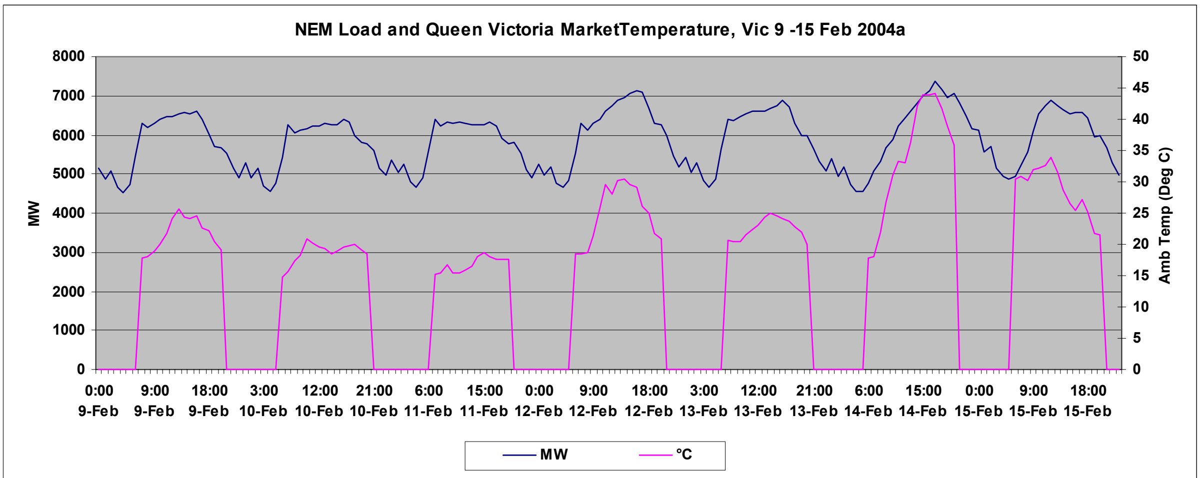
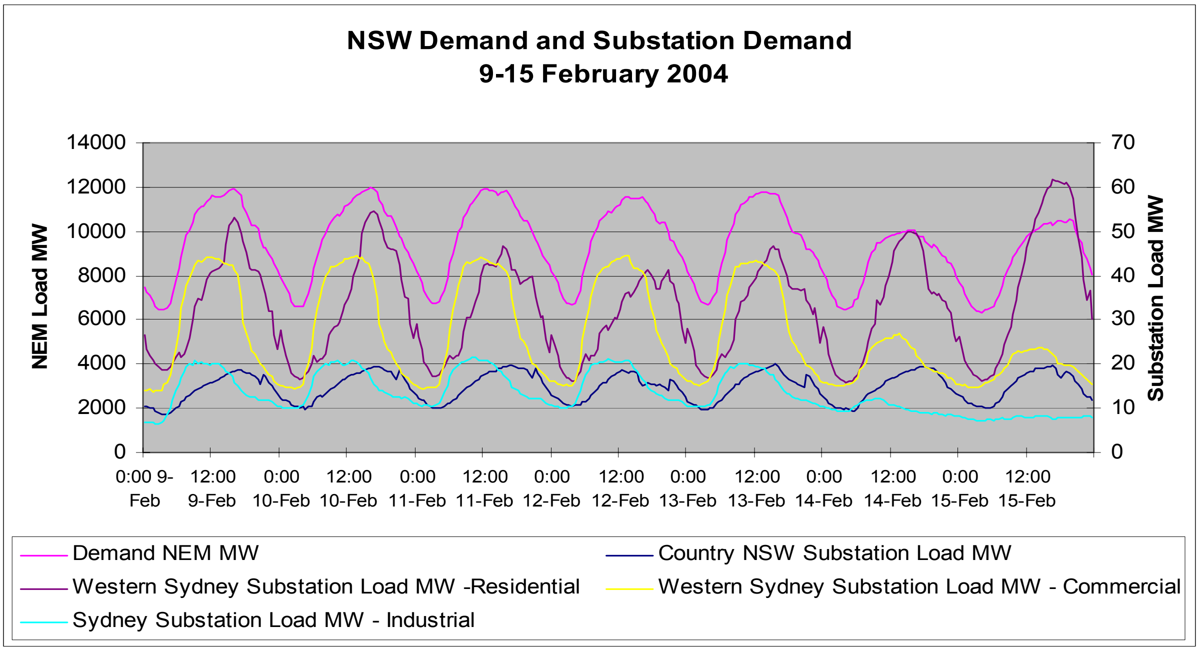


Figure 7: Temperatures and Loads at Regional NEM nodes for NSW, SA and Vic for the week 9-15 February 2004.

Note that for the Vic site, data is logged only when the PV system is operating, hence there are no night-time temperature values.

Residential transformer data for SA shows that on Saturday and Sunday 14 and 15 Feb the residential and SA load profiles are very similar, which is to be expected since commercial and industrial loads are at a minimum. It is interesting to note that the peak on the residential transformer in SA increased by 2.5 times between 9 and 15 February. In NSW, the residential transformer load in Western Sydney increased significantly over 14 and 15 February, although the overall State demand shows a more typical weekend pattern. The load on 15 February is higher on the Western Sydney residential feeder than it is on 14 February, as is the temperature (37 C rather than 34 C). The weekend load is higher than the peak weekday load, perhaps because the temperature midweek peaked early then dropped fairly rapidly from its peak value and was at a more comfortable level by the afternoon. State-wide loads are compared with feeder loads in Figure 8 and temperature and feeder loads are shown in Figure 9.



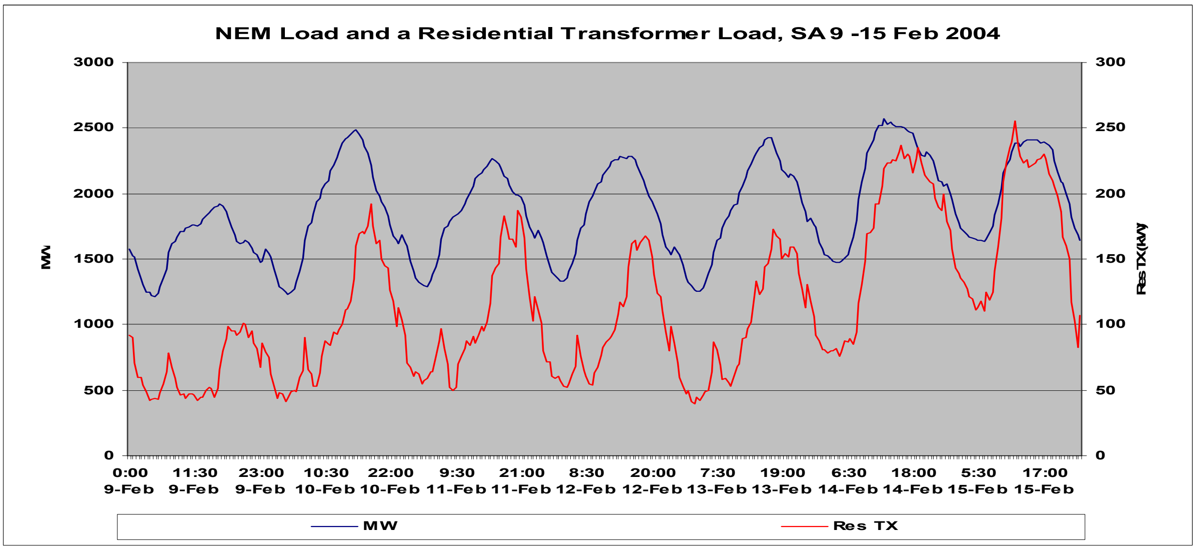
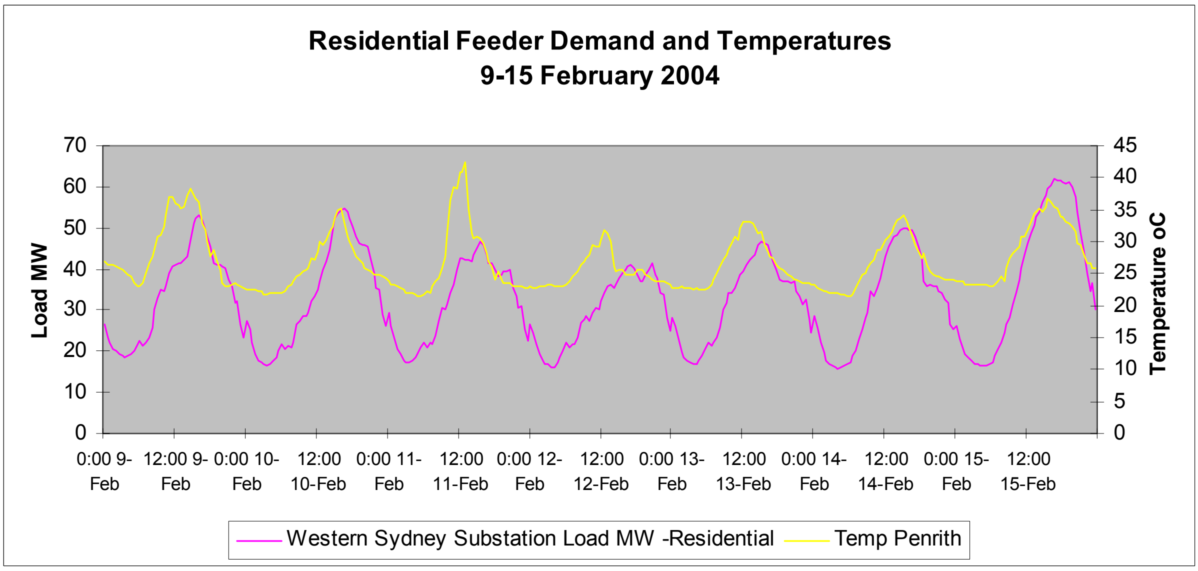


Figure 8: NSW and South Australian System Load and Feeder Loads for the Week 9-15 February 2004.



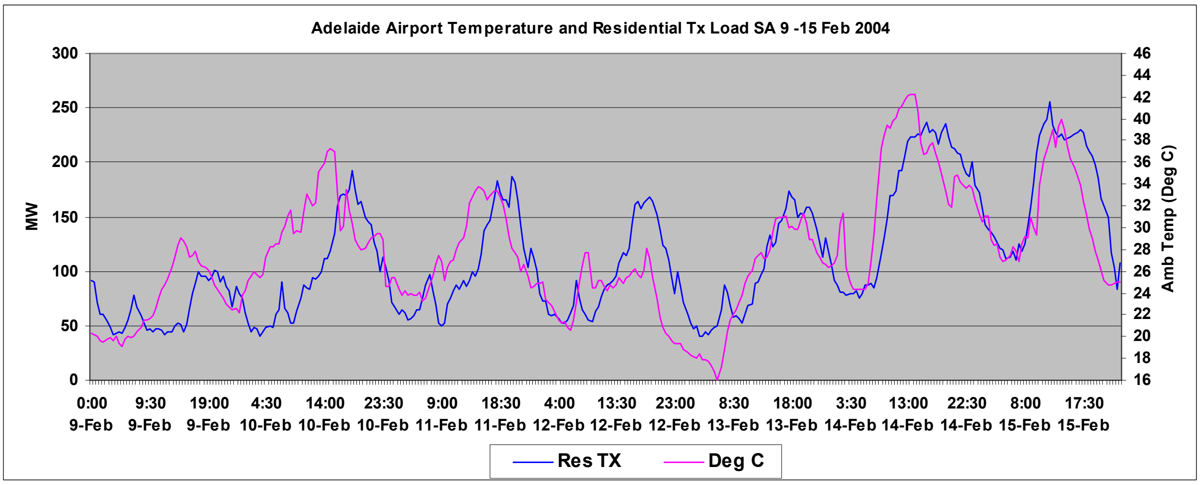


Figure 9: Substation Loads and Temperature 9-15 February 2004.

3.2 PV output and peak electricity loads

Figures 10 – 12 show PV output and peak summer loads for different feeders, while Figures 13-15 show PV output and total system peak loads in NSW, South Australia and Victoria. For the week 9-15 February, it is apparent that there was more cloud cover in Melbourne than in Adelaide or NSW and that temperature did affect PV output somewhat. Nevertheless, Figures 12-14 also show that, when cloud cover is low, PV and both system and commercial load profiles are a reasonable fit – better than for the residential transformers whose peaks last longer into the evening. This reinforces the fact that commercial rather than residential loads have profiles that better match those of PV, unless the PV array orientation is moved from north to west.

Peak periods can last as late as 7 – 10 pm, especially on week days in Victoria. Though the PV output obviously does not last as long into the evening as the electricity demand peak, it is possible that a combination of demand management and PV orientation can ensure PV provides some effective demand reduction over the majority of the peak period, as well as reduced transformer temperatures.

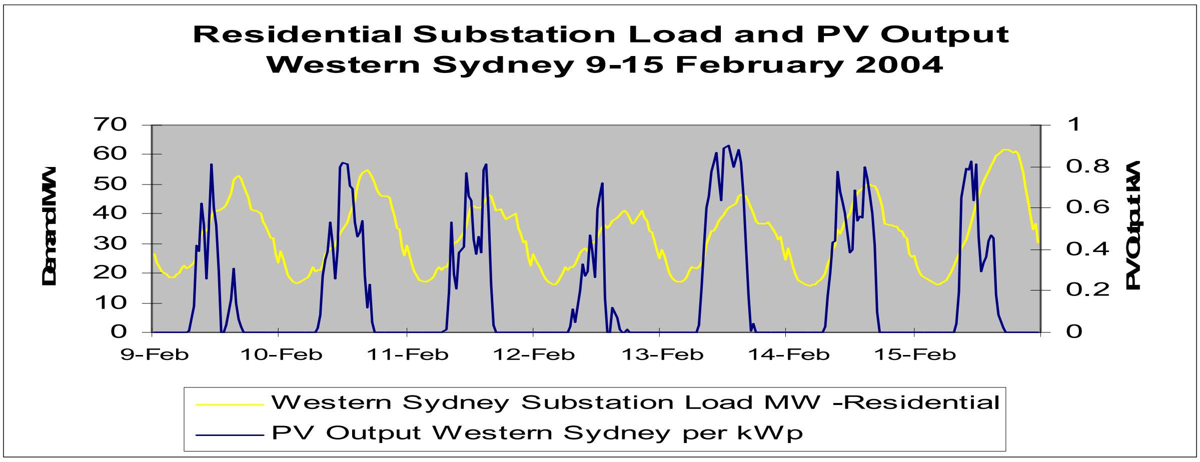


Figure 10: PV output and load for a Western Sydney residential feeder over a week of high demand - summer 2004.

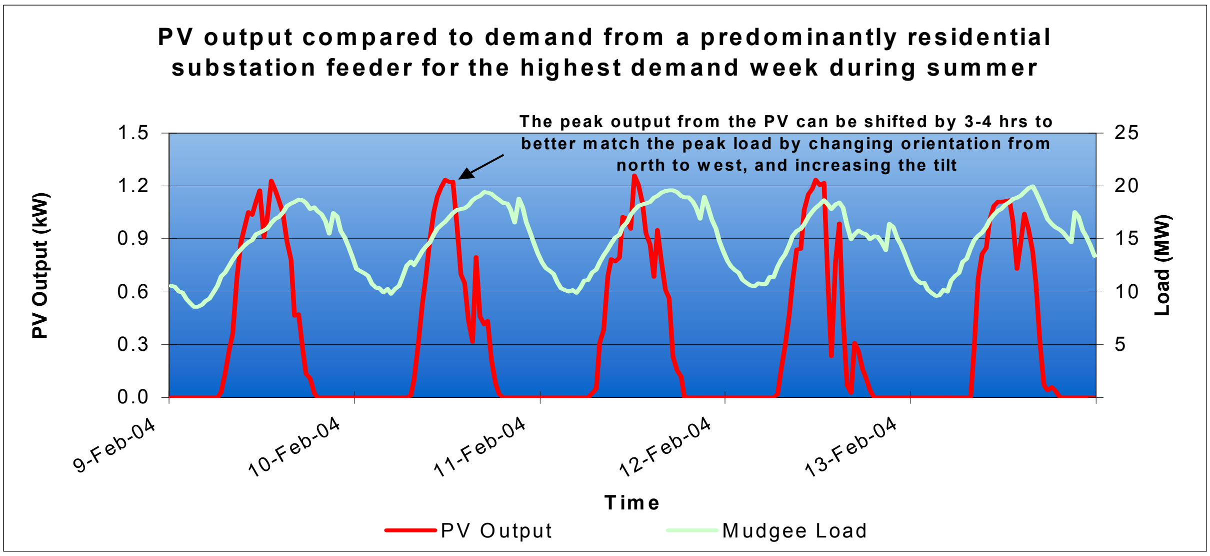


Figure 11: PV output and load for a NSW country town feeder over a week of high demand - summer 2004.

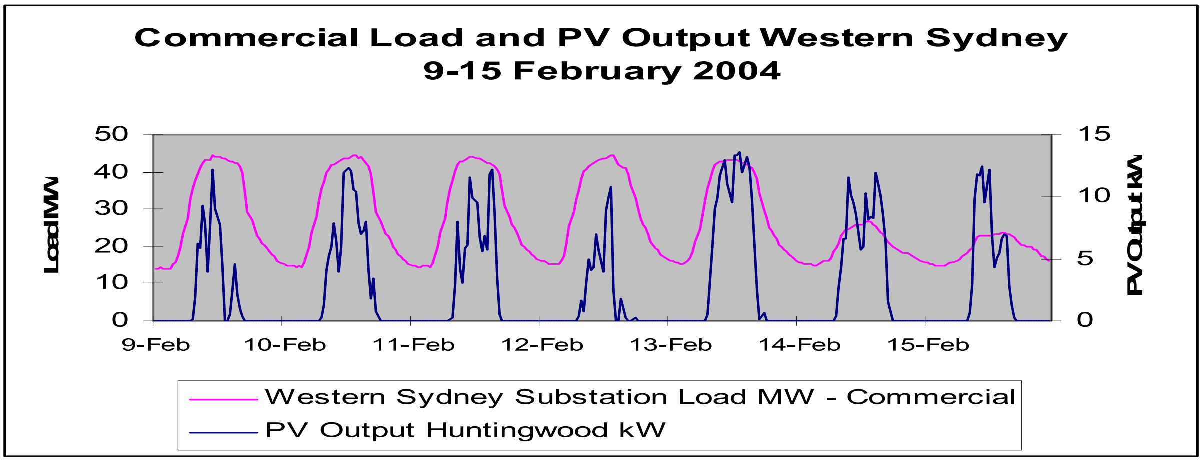


Figure 12: PV output and load for a Western Sydney commercial feeder over a week of high demand - summer 2004.

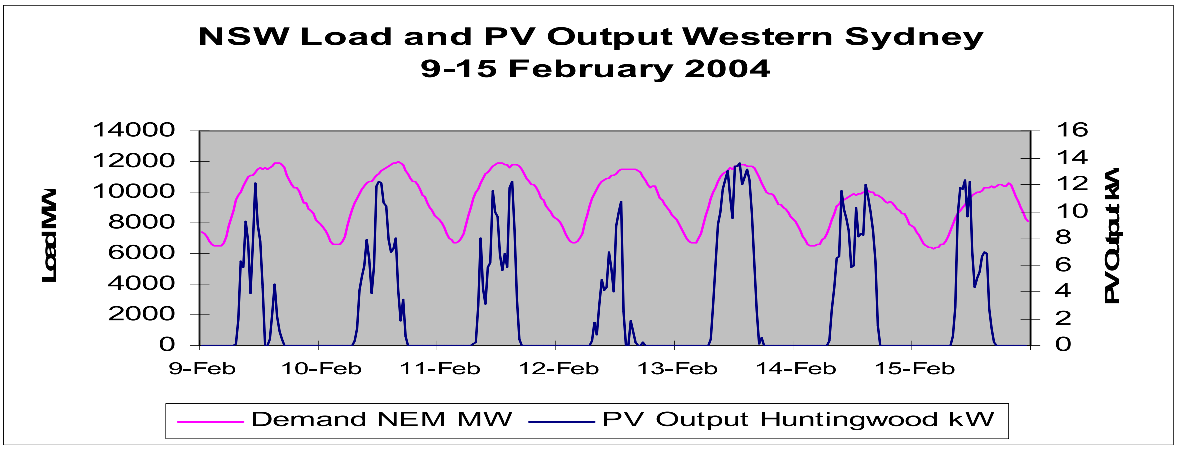


Figure 13: PV Output and NSW Load over a peak load week summer 2004.

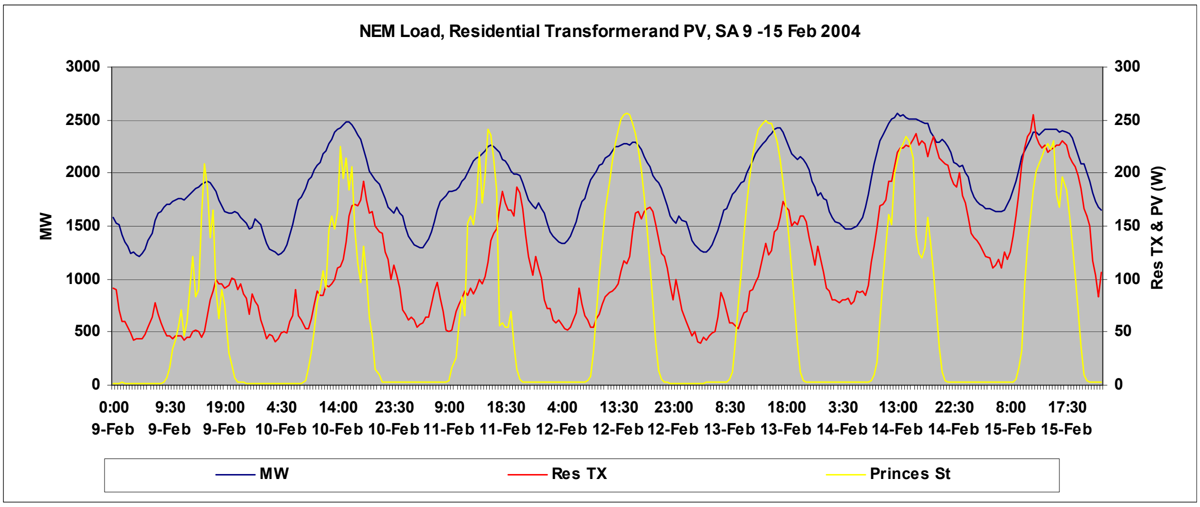


Figure 14: PV Output and both system and residential feeder loads in South Australia 9-15 February 2004.

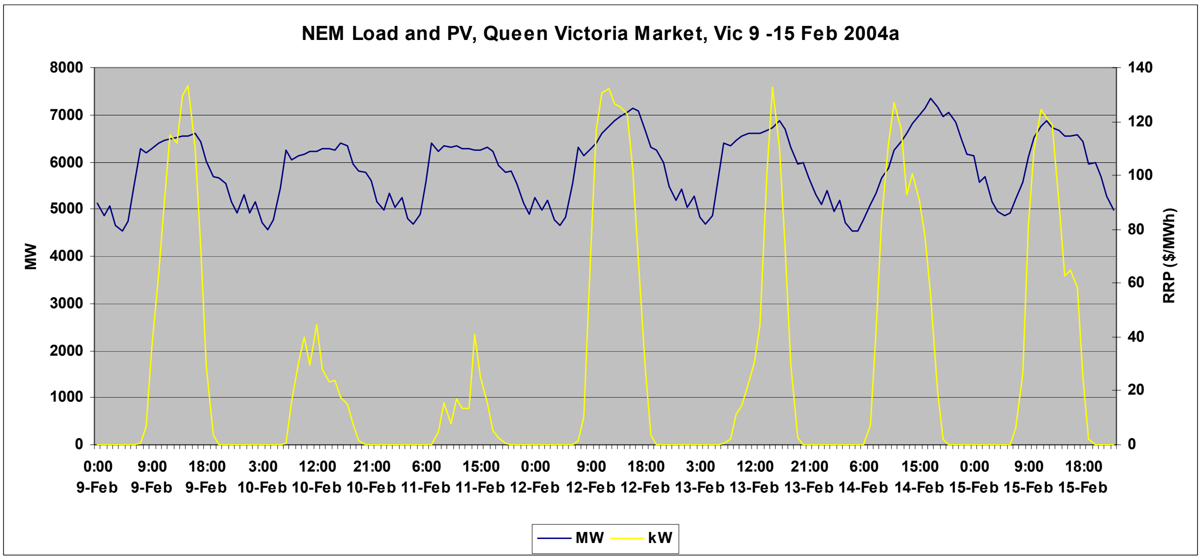


Figure 15: PV output and system load on a peak summer week in Victoria – summer 2004.

3.3 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. 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 16.

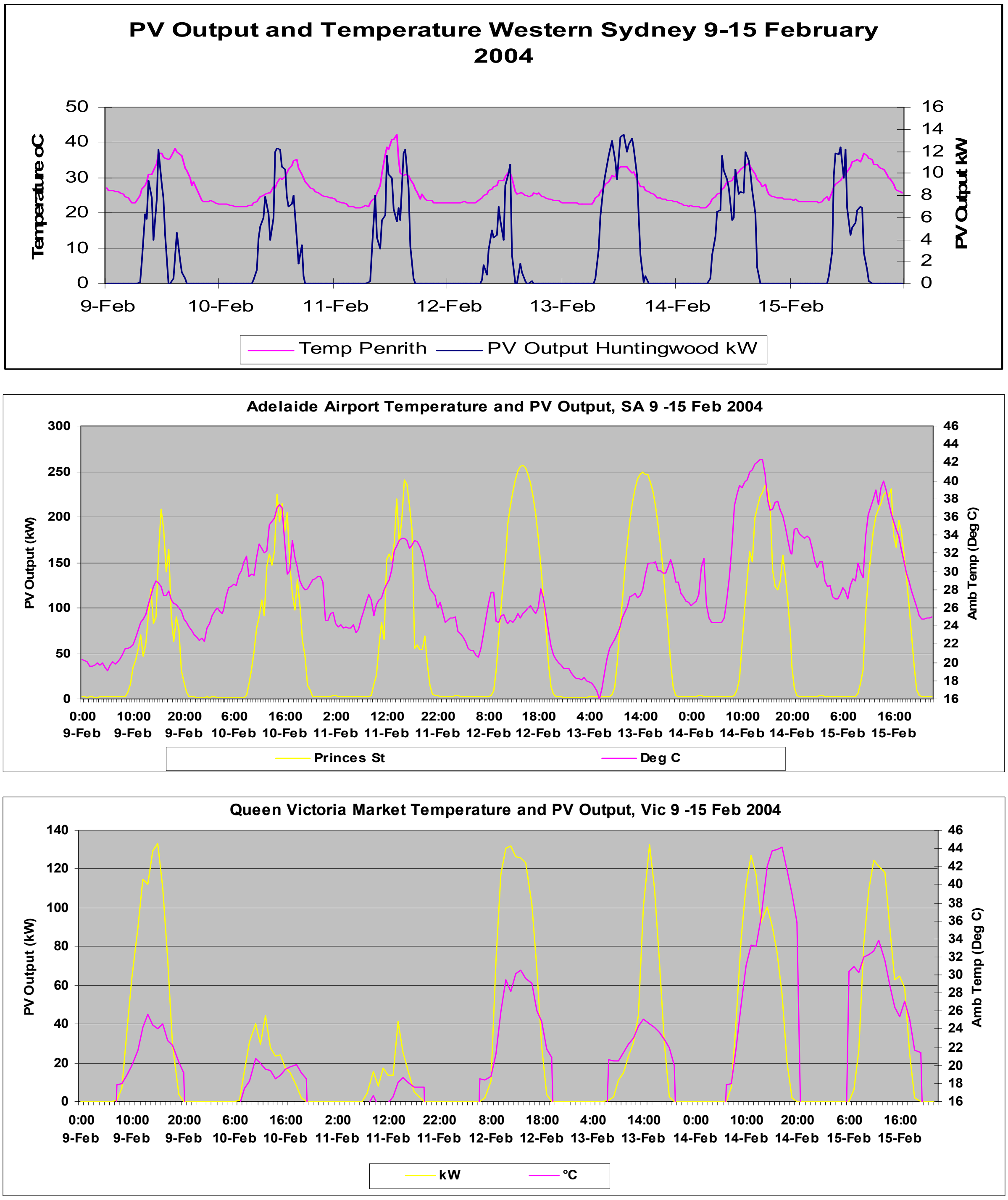


Figure 16: PV output and ambient temperature over a peak load week.

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 17 shows the load and the load reduced by an appropriately sized PV array for feeders with predominantly residential loads.

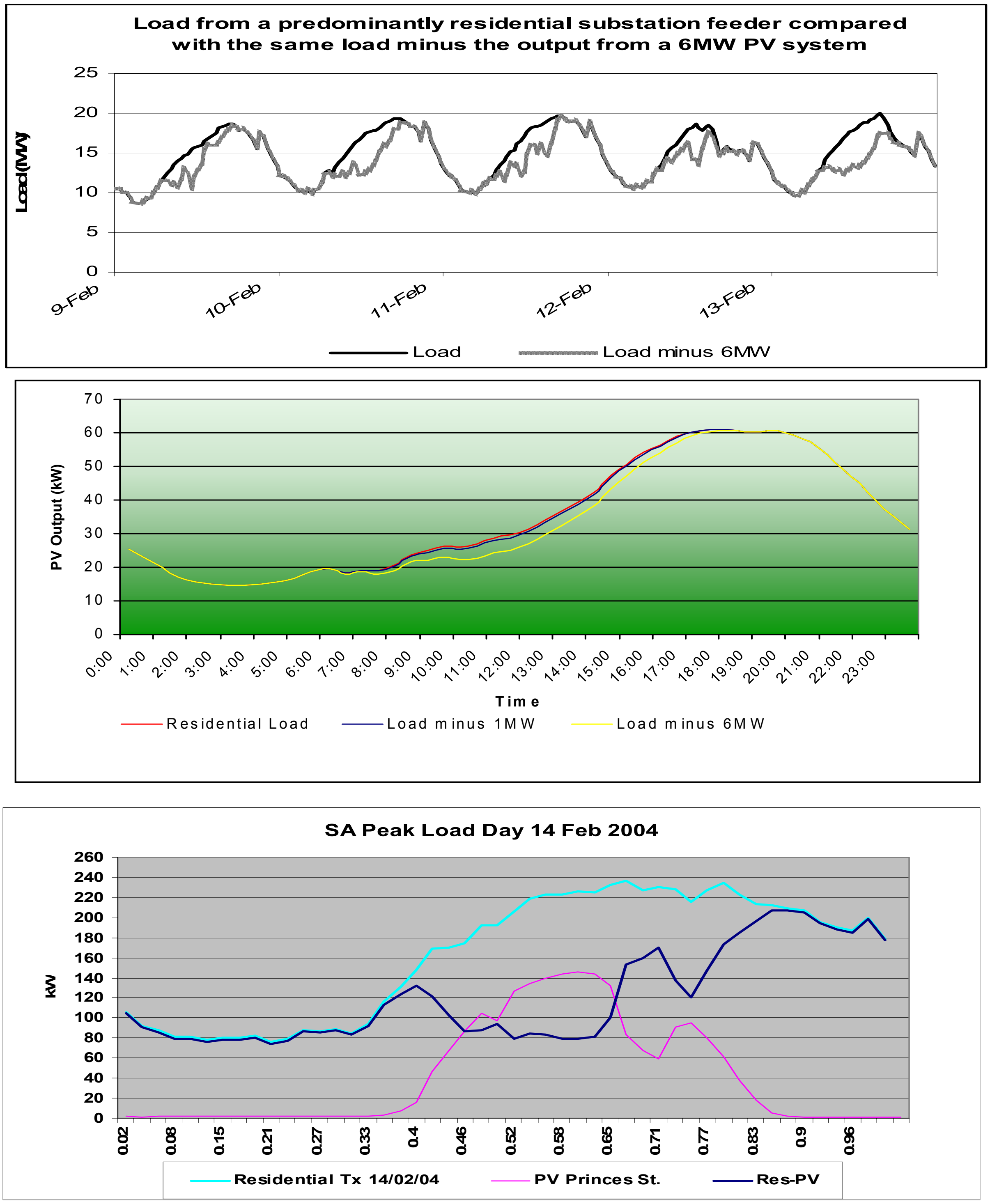
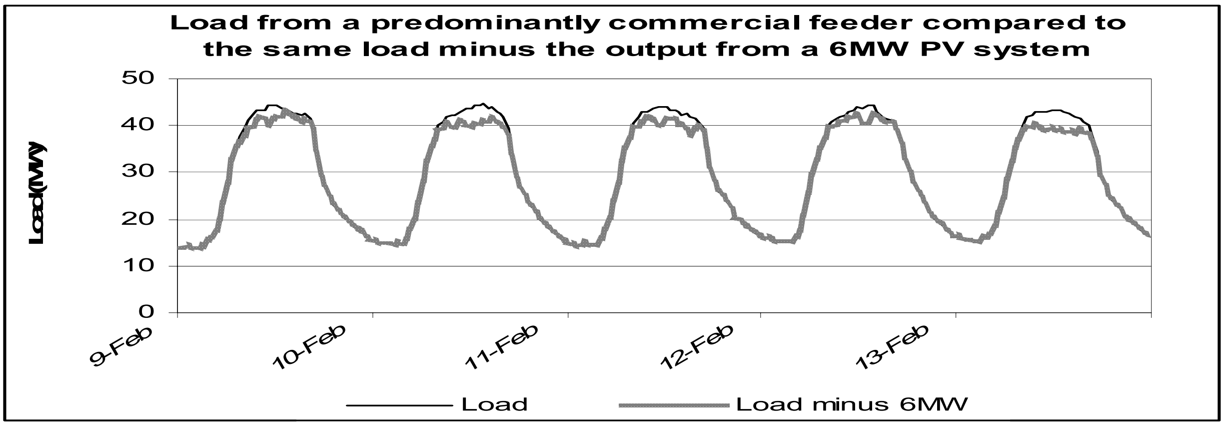


Figure 17: Potential PV contribution to residential load during peak demand.

For feeders with a mixed load, including commercial and industrial, and for the overall system load, the PV contribution can be more useful. Figure 18 shows the impact PV could have on a commercial feeder load and Figure 19 the impact on total system load.



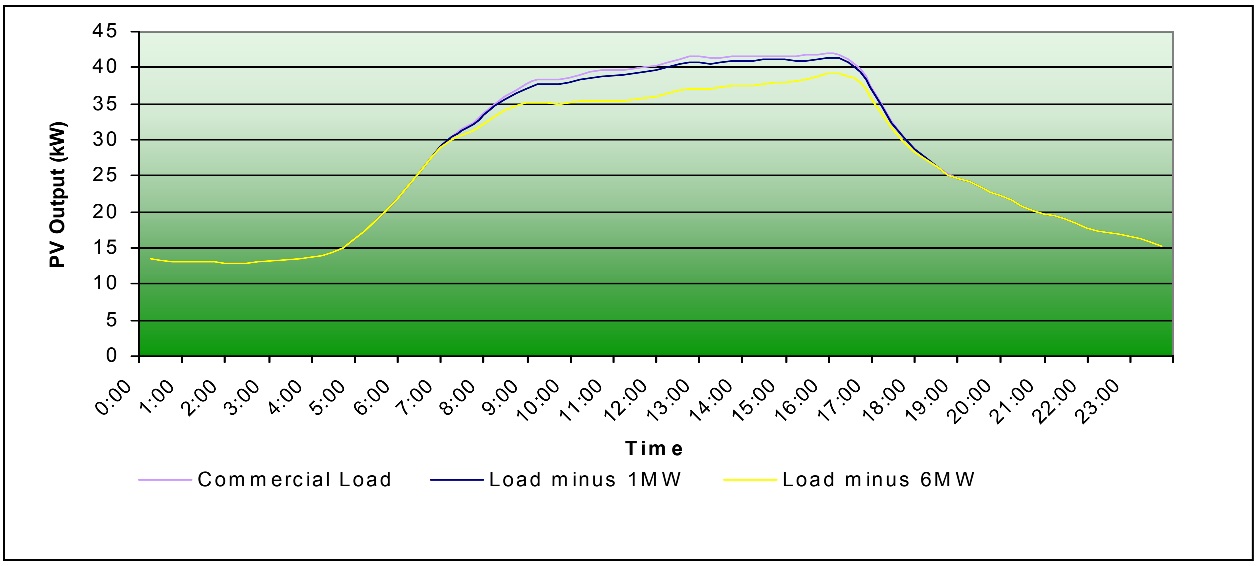


Figure 18: Potential PV contribution to commercial load during periods of peak demand.

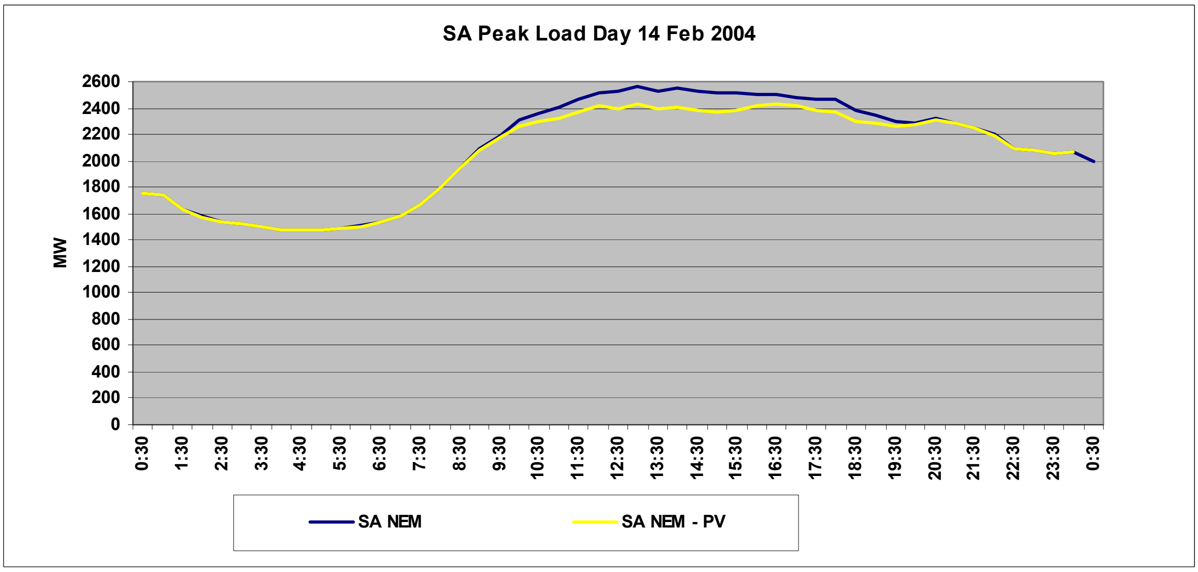


Figure 19: Potential PV contribution to system load on a peak load day.

3.5 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 20 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 21 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.

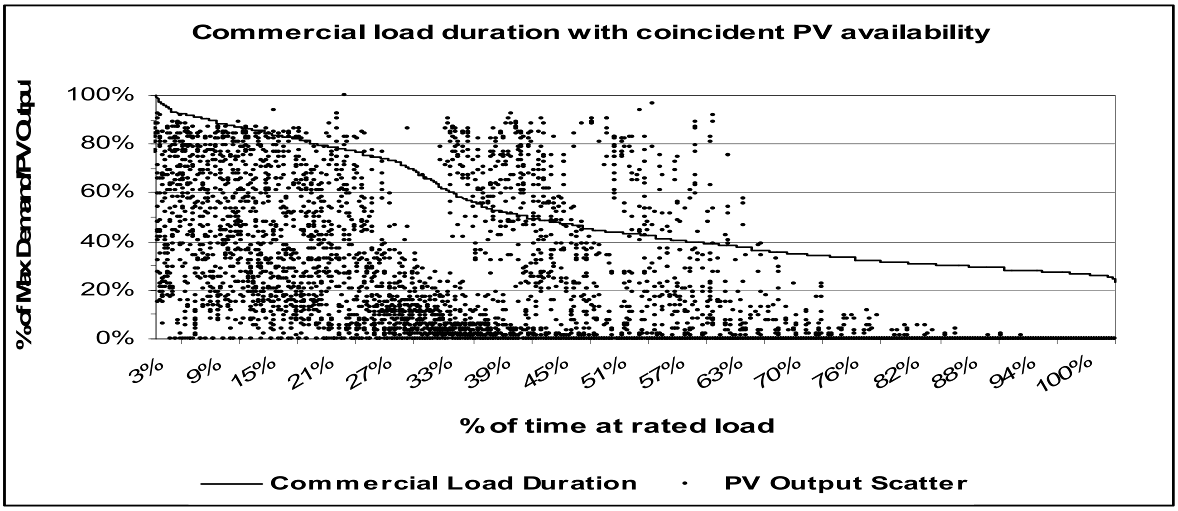


Figure 20: Normalised load duration curve for a commercial feeder in Western Sydney with coincident PV output - Summer 2003-04.

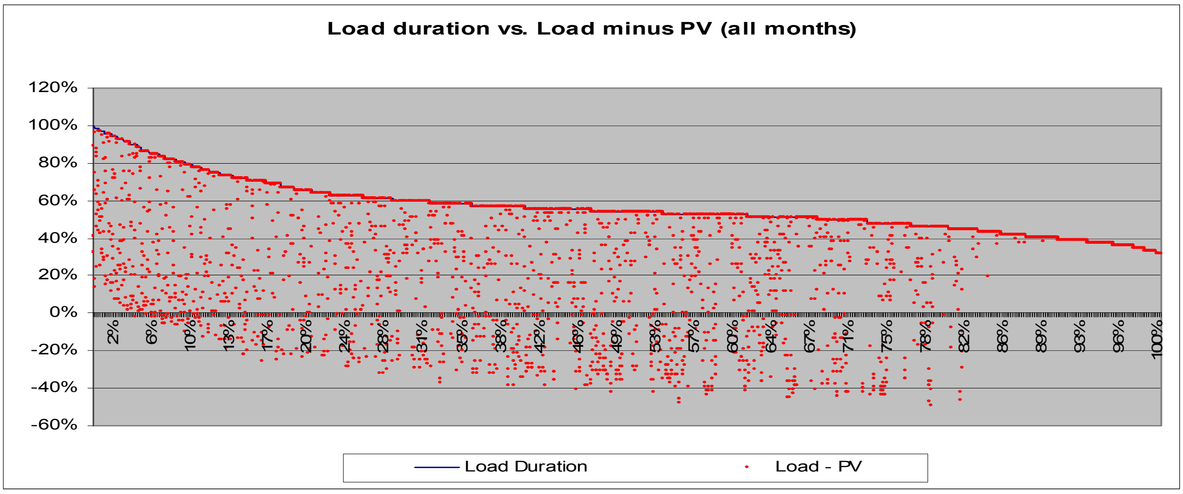


Figure 21: Normalised load duration curve for a NSW country town feeder showing the potential load reduction due to coincident PV output - Summer 2004.

Another way of assessing network value is to correlate PV output with load. Figure 22 shows this correlation for a PV system in Adelaide with the household's own load over the time period 14:30-15:30, which shows high correlation, while Figure 23 shows lower correlation over a longer time period.

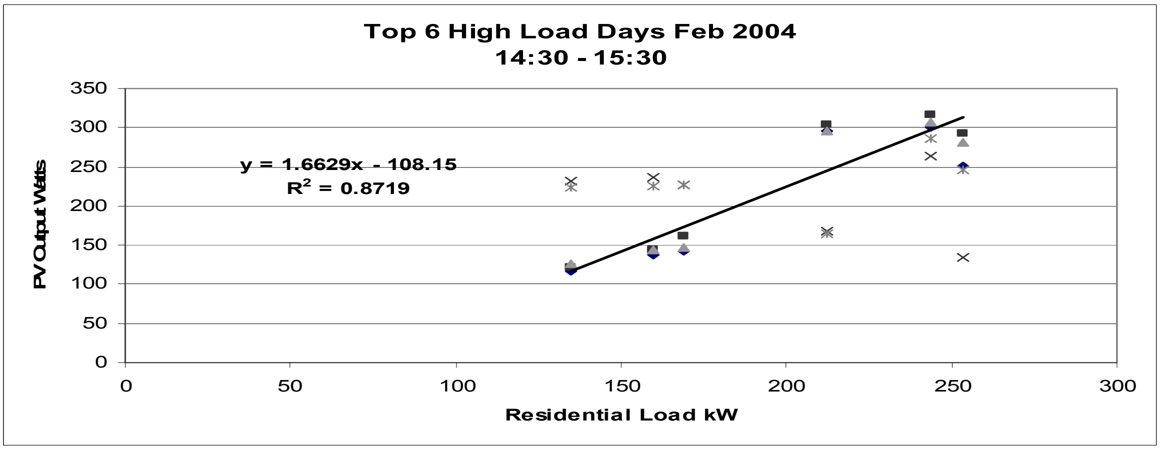


Figure 22: PV correlation with household load in Adelaide (no air conditioning) (R^2 = 0.87) - Feb 2004.

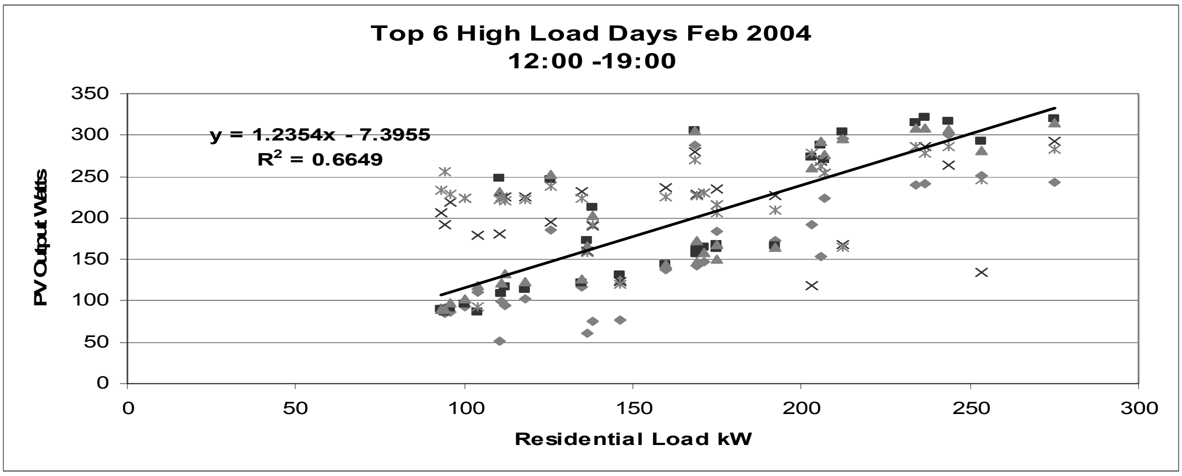


Figure 23: PV correlation with household load. Adelaide (no air conditioning) (R^2 = 0.66) - Feb 2004.

3.6 *Assessing Retail Value*

Peak summer days can see spot prices on the National Electricity Market (NEM) rise substantially. If PV can contribute to load during these surges, it will be of increased value to retailers. Figure 24 shows PV output and NEM price during a peak summer temperature week in New South Wales, South Australia and Victoria.

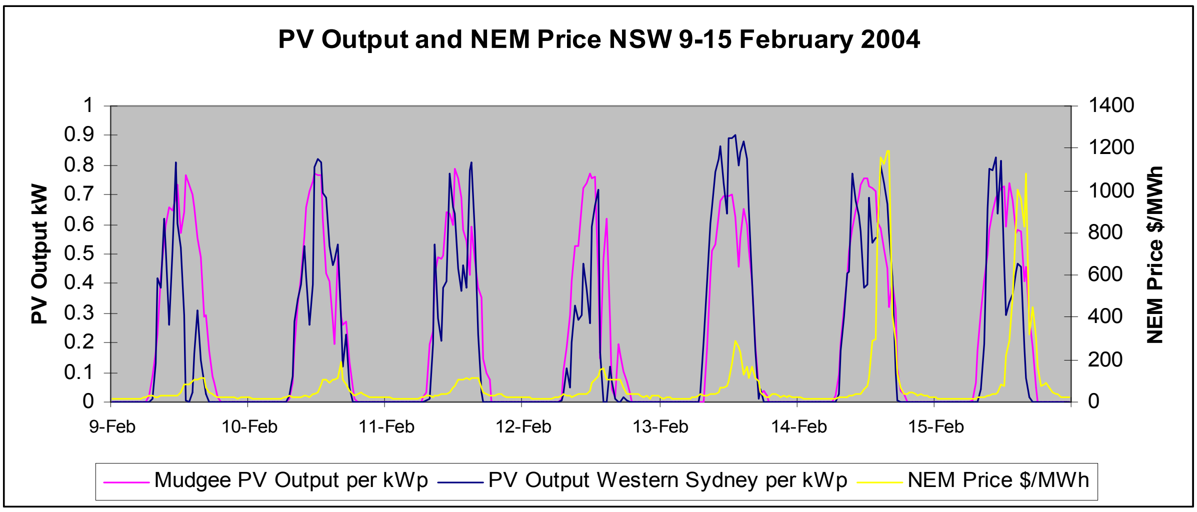


Figure 24a: PV output and NEM price for a peak temperature summer week in NSW – Summer 2004.

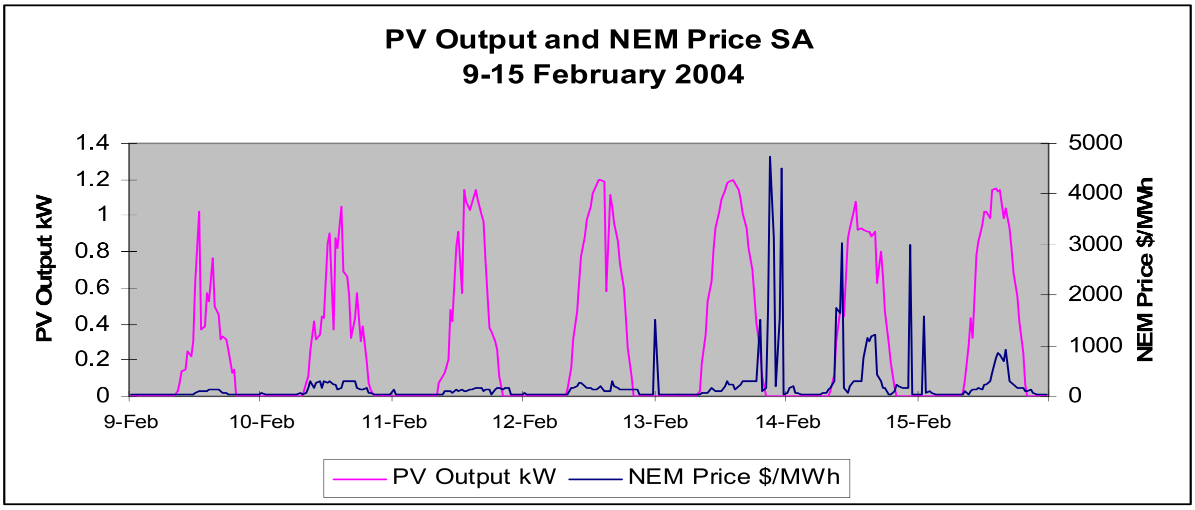


Figure 24b: PV output and NEM price for a peak temperature summer week in SA – Summer 2004.

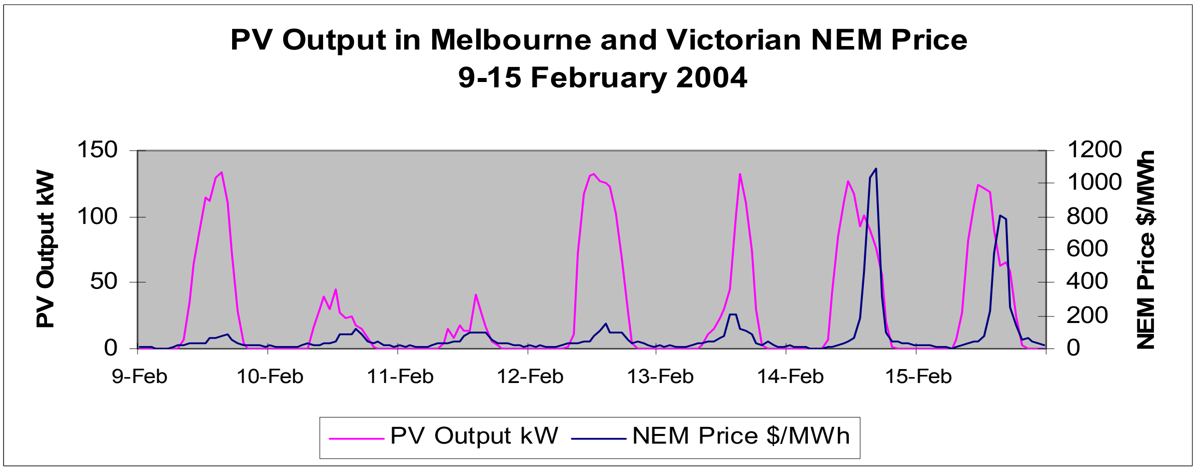


Figure 24c: PV output and NEM price for a peak temperature summer week in Vic – Summer 2004.

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 the 2003-04 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 also correlate well with their 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. This may be in the form of electrical or thermal storage. Earlier studies [1, 5] have shown that west facing arrays, with higher tilt angles would allow the PV load curve to be shifted towards the afternoon, with the PV output peak in Sydney moving from noon for a north facing array to 3pm for a west facing 45 degree tilt array. Summer PV energy production is not greatly affected by this change in orientation, compared to a north facing array at 35 degree tilt, however, winter energy production is reduced, as is overall annual output. Hence, if the electricity industry wishes to encourage summer output, PV system owners would need to be compensated for lost winter revenue by higher summer revenue.

A key requirement also is the need for improved residential building energy performance, so that overall cooling needs can be reduced. This should include greater use of insulation, as well as appropriate building orientation and shading on north and west facades over summer. One BIPV option may be PV window shades or pergolas for west facing walls.

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.

4.1 Future Work

Further work in this area could be undertaken to quantify the wider benefits of distributed grid connected PV in an infinite grid network over time, particularly in grid constrained sections of the network, so as to be able to develop a position to input to the Solar Cities trials and to various reviews of DNSP regimes being undertaken around Australia.

The following aspects may be addressed:

- The monetary value of pre-cooling Transmission and Distribution systems during the summer peaks

- The monetary value of offsetting the Transmission and Distribution losses at summer peak
- The monetary value of VARS provided by PV, particularly in high inductive load areas
- The monetary value of network upgrade deferral (both generation and distribution infrastructure) eg what is the marginal cost of the last kW to meet a peak load
- Development of a value chain of a PV kW, kWh and VAR over the summer months from end use customer, through PV system owner (if different), electricity retailer, network service provider and society as a whole. In doing so, a number of issues will need to be examined for each participant:
    - different measures of 'value'
    - current value against potential future values
    - uncertainty and risk
    - difference between prices and costs
- the marginal value of a single 1kW PV unit on its own or as part of a much larger aggregated number of systems
- Investigate the level of PV needed to defer traditional investment in networks in the supply constrained areas of NSW, Victoria and South Australia, including:
    - line capacity for the house, transformers on the street and local substations.
    - Newington, as an example of high penetration levels
    - investment costs in PV compared with traditional supply based approaches
    - Different technical approaches to maximise value of PV – orientation, cooling
- Identifying the policy and institutional barriers preventing any premium value of PV being captured by the various participants
- How would a significant uptake of PV enhance the reliability of the grid (what is the scale factor? Is there a minimum amount before the effects can be quantified?)
- What value is there in an infinitely scalable technology, widely distributed vs highly concentrated large MW generating units.
- Would PV work as an effective offset to AC units, if so how and quantify.
- What government policies (State and Federal) effect the uptake of PV (both + and -), how does PV output match system ratings and modelling and how does it match the MRET deeming levels.
- How does PV ownership impact on electricity / energy consumption. Is there evidence PV ownership drives additional energy efficiency.
- Examine the time of day value of a PV kWh, over the entire year including:
    - Overall contributions to household electricity needs
    - winter peaking issues
    - growing use of reverse-cycle AC for winter heating.
- Investigate the possible values of a kWh saved due to associated energy efficiency / demand management measures.
    - What energy efficiency measures could be built into a PV program to further add value - eg PV and lighting upgrades, PV and roof insulation upgrades.
- Investigate storage options and value for grid connected PV
- What customer feedback loops might be effective – ie. Increased energy awareness
    - Undertake customer surveys and further analyses to assess best options for future roll out, especially with combined energy services.

5. References

[1] Watt, M. E., Oliphant, M., Outhred, H. & Collins, R., 2003, "Using PV to Meet Peak Summer Electricity Loads", *Proceedings of Destination Renewables, 41st Conference of the Australian and New Zealand Solar Energy Society,* Melbourne, November, 2003.

[2]Charles River Associates, 2003, *Impact of Air Conditioning on Integral Energy's Network*, Report to Integral Energy, May 2003, www.integral.com.au.

[3]Nethercote, I., 2003, "Economic outlook provides sober underpinning for the argument that government leaders must make key energy policy decisions in mid-2003", *Electricity Supply Magazine*, ESAA, January 2003.

[4] IPART, 2002, Inquiry into the Role of Demand Management and Other Options in the Provision of Energy Services – Final Report. Review Report No Rev02-2, www.ipart.nsw.gov.au.

[5] Watt, M., Kaye, J., Travers, D., MacGill, I., Prasad, D., Thomas, P.C., Fox, E. & Jansen, S., 1998, *Opportunities for the Use of Building Integrated Photovoltaics in NSW,* Report to SERDF.

Appendices – Site Data

New South Wales Sites

Site 1. Mudgee
Site 2. Blaxland St, Newington
Site 3. Heidelberg St, Newington
Site 4. Harbord
Site 5. Huntingwood
Site 6. Queanbeyan

Victorian Sites

Site 7. Queen Victoria Markets

South Australian Sites

Site 8. Princes St
Site 9. SA Museum
Site 10. Willunga
Site 11. Magill
Site 12. Mark
Site 13. Don