Kogarah Town Square Photovoltaic Power System

Demand Management Analysis

1 September 2005

EnergyAustralia™

Contents

1 Executive Summary

During January, February and March 2004 measurements were taken of a 160kW Photovoltaic Power System (PVPS) installed at the Kogarah Town Square site. The purpose of this study was to evaluate the effectiveness of PVPS as a peak demand reduction option that could reduce new network infrastructure installations.

The study showed that the system was able to provide some reduction in peaks that fell in the middle of the day. There was a good correlation between the peak of the KTS site and the time of peak PVPS power production. For the period studied, there was a reduction in demand of 45kW, or 9.1% of site demand. This reduction represents 35% of the available PV capacity. This low proportion is due to the relatively low output of the PV in the afternoon while site demand was still high and to the variability in PV output during its peak period. Comparison of the PV profile to the local network (Carlton Zone) profile suggests that a wider installation of PV would produce similar results at the Zone level. If anything, the typically flat load profile of the zone would tend to reduce the relative contribution of the PV to reductions in demand.

Several limitations of the PV installations' ability to reduce network peak demand were revealed by the study. The PV power production was heavily dependent on weather conditions and its contribution to demand was limited to the middle of the day. The amount of power produced by the PVPS during the peak varied widely between 3.5kW and 80.8kW. Consequently, the installation had much less impact on demand than its nameplate rating. Several of the inverters were found to have failed during the period. While the failures are considered non-typical, they indicate that the general assumption that PVPS are maintenance free was not strictly true. Monitoring and maintenance was required to maintain reliable performance.

No evidence was found to support a view that energy produced by the PVPS had a significantly higher electricity market value than offered by current tariff rates. The buyback rate commonly offered by retailers is 11c/kWh while the value of the energy produced by the PV priced at the half hourly spot price was only 7c/kWh.

The study was limited to summer months so the applicability of PV to assisting with winter peaks has not been evaluated.

2 Project Aim

To evaluate the effectiveness of the KTS photovoltaic system as a network peak demand reduction option.

Correlating the demand profile of the entire site and the production profile of the photovoltaic power system (PVPS) enabled evaluation of the contribution the PVPS makes towards reducing the site's peak demand. The potential impact on peak demand at Carlton Zone can be inferred by comparing the PVPS production with the zone profile. While PVPS can be used as a greenhouse gas reduction strategy, it is only of value in terms of network infrastructure reduction if it causes a reliable reduction in peak demand.

A secondary aim was to attribute a market value to the power produced by the PVPS to determine whether the level of coincidence between high pool prices and PVPS production meant the energy from the PVPS has a significantly higher value than current buyback tariff rates.

3 Overview of the Kogarah Town Square Site

The Kogarah Town Square (KTS) site is a combination residential/commercial establishment located in Kogarah in the southern suburbs of Sydney. It is located on the block surrounded by Belgrave St, Kensington St, Derby St and Post Office Lane, just to the south of Kogarah railway station. The development consists of three blocks of four to six stories, with underground parking comprising:

- 193 residential dwellings
- 2461 m^2 of retail area
- 2176 m^2 of commercial office area
- 1405 m^2 of council space
- car parking comprising of 230 residential, 117 commercial/retail and 224 public spaces

Kogarah Council commenced the project as part of their “wider urban renewal program”; with Hightrade Construction Pty. Ltd. being the primary contractor. Incorporated in this project was the Solar Kogarah Initiative, created to explore opportunities for promoting the development of solar energy into urban renewal schemes. EnergyAustralia won the tender for work involving the system design and supply of:

- PV laminates and roof sheeting (to meet the BIPV requirements)
- Roof insulation
- DC wiring and connections
- Inverters

The contract was signed May 2001, and the system (with nominal capacity of 160kW) was commissioned in April 2003.

3.1 Building Integrated Photovoltaics

Unlike most photovoltaic systems, in BIPV the photovoltaic modules form part of the roof and are not a post construction add-on. The KTS BIPV power system design primarily used Uni-Solar PV modules, which are flexible and lightweight modules that were bonded to conventional metal roofing panels. The other PV modules used were Solar Nova Glass/Glass PV laminates, which form the skylight section of the council space and the street awnings.

The PVPS has an area of 2800m^2 and a peak capacity of 160kW. This roof area is primarily of a 20^0 pitch with a small area of 10^0 pitch. The general building orientation is 53^0 west of north, with some roof sections at bearings of 100^0, 190^0 and 280^0.

The BIPV power system comprises of the following components:

- 1358 Uni-Solar PV modules (964 x 128W and 394 x 64W)
- 104 Solar Nova Glass/Glass PV modules
- 58 Sunpower SP1200 and SP2500 inverters (which are 1.2kW and 2.5kW modules respectively)
- A monitoring and display system

Energy is generated by the action of the sun on the photovoltaic modules. The direct current (DC) is converted to alternating current (AC) by the inverters. The inverters of the PVPS are in 15 groups situated in cupboards and rooms around the site. The inverters are connected via meters into distribution boards of the house services circuits.

3.2 Load Type

A detailed analysis of the power usage and demand within the site was beyond the scope of this project; however a basic review was carried out by inspecting the site wiring diagrams and other available information. This enabled a breakdown of the load components of the site, which is as follows.

3.2.1 Residential Space:

- All 193 apartments were occupied as at 28th January 2004 (Source: Richardson & Wrench)
- None are connected to the building air conditioning system.

3.2.2 Commercial/Retail Space:

- Of the 33 spaces, 20 were occupied as at 20th January 2004 (Source: Network Strata Services)
- All are connected to the building air conditioning system

3.2.3 Council Space:

- Currently unoccupied

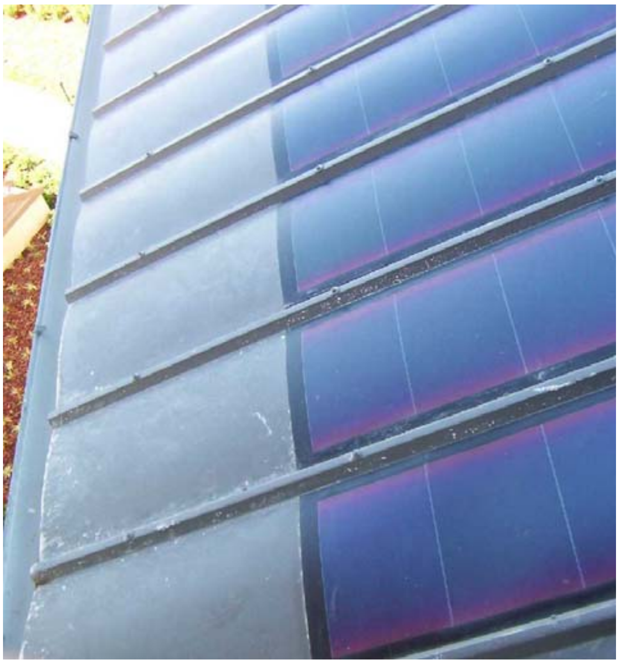
3.2.4 Significant Loads

- Chillers and water pumps (343kW) for the commercial and retail space
- Car park motor control centres (144kW)
- Cooling tower (11kW) associated with the chiller
- 10 lifts (kW unavailable)
- Fire control room and fire hydrant pumps (kW unavailable)

3.3 Photos

Artist drawing of entire site (Kensington St on left, Belgrave St at bottom)

View towards Kensington St from the roof on the north side of the Plaza



Close-up of PV Modules on Roof Panels

Inverter Group

4 Project Procedure and Setup

The two primary sources of data for this project were the power production of the PVPS, and the power supplied to the site from the local substation dedicated feeder. To compliment these figures and aid in explanation of their characteristics, data was obtained from the weather monitoring system at the KTS site and the Carlton zone substation, which supplies the site. These sources are explained below, followed by an explanation of the methods used to correlate the data sources. An electrical line diagram of the relevant components for this project is given in Appendix A. Times are in Australian Eastern Daylight Saving Time.

4.1 PVPS Power Production

The operation and production of the PV modules are monitored by an on-site PC located in the Manager's office. This is done by an RS485 connection to each of the inverters at the site, allowing logging of the power production. The data is displayed on both the PC and public display, and is logged to text files by the Sunpower HMI software. Daily data files contain 15-minute data for all 58 inverters. The weather station data is accessed via modem connection.

4.2 Local Substation Dedicated Feeder

To log the power supplied to the site from the electrical grid, a power logger was installed in the local substation on the dedicated busbar feeding the KTS site. The substation, S.10801, is located on Post Office Lane and is fed from panel 18 of the Carlton Zone Substation (Sub Number 175). The logging was performed using a TCA Polylogger II; a six-channel microprocessor based data logging instrument. The logger records 3-phase volts, amps, real and reactive power, and the power factor.

The logger data can be downloaded onto the laptop through the serial port, using the Polylogger II communications software. This information is then converted to a delimited text file (recognisable by Microsoft Excel) allowing collation with the other data. The Polylogger measures Real Power per phase, which is summated to obtain the total three-phase power.

4.3 11kV Carlton Zone Substation Load

The load seen at the Carlton Zone substation (Sub Number 175) was measured. This data was retrieved from the EnergyAustralia network data acquisition system in the form of 15-minute phase currents. For simplicity, these currents are converted to MW using the average zone power factor (0.89) and nominal line-line voltage (11kV).

4.4 Weather Monitoring

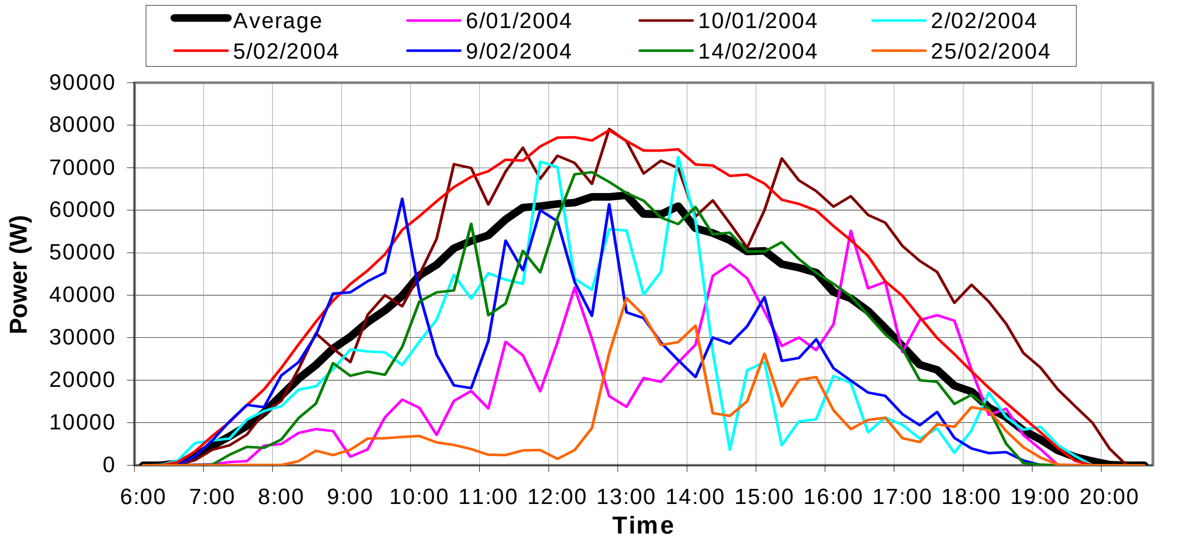
The KTS site also has a weather monitoring system, with data recorded on the same monitoring PC as the PV power production. This data enables further understanding of the variation of load and PV data with the solar radiation, ambient temperature and relative humidity. There should be a very close relationship between the solar radiation and the PV power production.

5 Results

5.1 PV Production

Between the 6 January and 17 March 2004, the average daily PV production was 473kWh with 21.8MWh of power produced over the whole period. When considering the potential of PV for demand reduction, the main concerns are the time of peak production and the consistency of supply on peak days. The primary influence on PV production is incident solar radiation, although temperature, shading and the orientation of the panels will also affect output. Solar radiation peaks during the day when the sun is overhead and drops to zero at night. It is also highly dependent on daily weather conditions, especially the presence of cloud cover.

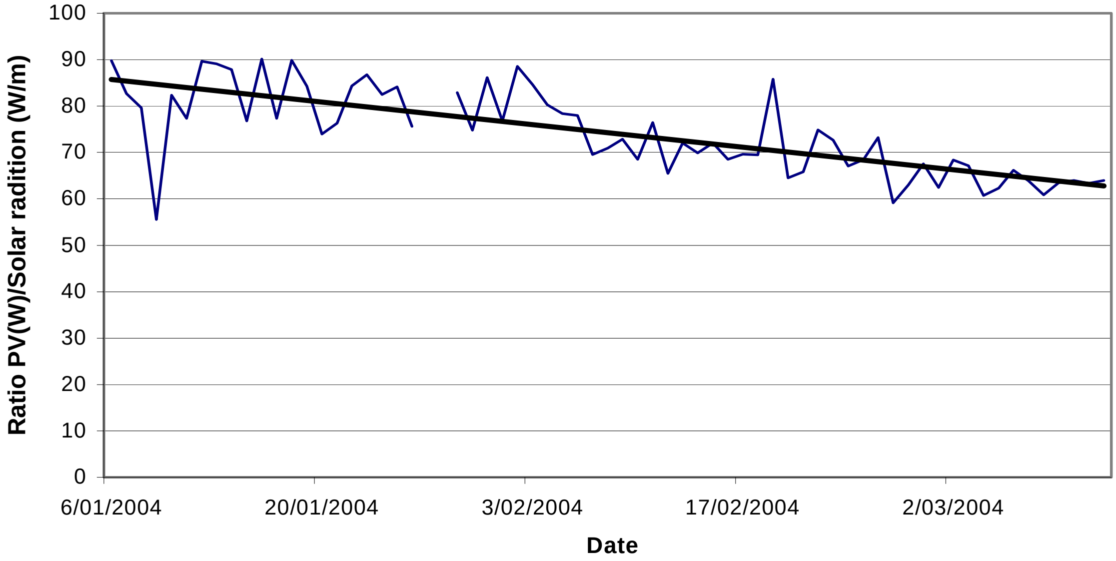
Figure 1: Average production profile for PVPS at KTS site. Several sample PV profiles are shown to give an indication of the variability in production



These influences are apparent in PV production profiles in Figure 1. In addition to the average profile, several daily profiles are shown to illustrate the variability in the PV output. The PV produced 90% of its power between 9am and 5pm with the peak most commonly occurring at 1pm. Output was significantly reduced from its peak level by 5pm. The PV output exhibited a relatively large variability throughout the day. It was common for the output to drop below 20kW during the day with outputs as low as 2kW observed during the peak 12pm-1pm period. Although we have no direct evidence, the most likely cause for these fluctuations was passing cloud cover.

Low PV Production: Taking into account shading, temperature degradation and the orientation of the panels, we predicted the maximum output to be 77% of nameplate capacity under ideal conditions. The measured maximum output of the PV was about 25% less than this. Investigation revealed an unusually high failure rate of the inverters. When commissioned (April 2003), all 58 PV/inverter sets were operating. At the beginning of the monitoring period, twelve (20.5%) of the inverters were not producing. On the last day of monitoring (March 17 2004) this number had increased to 23 (39.7%)[1]. The inverters failed gradually over the period. Figure 2 shows the ratio of daily PV output versus the daily solar radiation and shows the steady decline in available PV capacity over the period. This had not been detected by the system owner, and highlights that there is a need for ongoing monitoring and maintenance of photovoltaic systems.

Figure 2: Ratio of Daily PV/Solar Radiation



Due to the high failure rate, considering the PV production in terms of installed nameplate capacity would not accurately represent the performance of the PV. Instead, the PV production has been represented as percentage of a*vailable capacity*. The a*vailable capacity* on each day is the capacity of the operating PV panels at midday. The *available capacity* is used throughout this report to indicate the performance of the PV. The peak output of the PV was 74% of the *available capacity*, which agrees with the predicted value.

[1] The high rate of failure was found to be due to an underrated connection inside the inverters. No one was responsible for monitoring the PV system so the fault went unnoticed for several months. When identified the connections were repaired and have operated satisfactorily since.

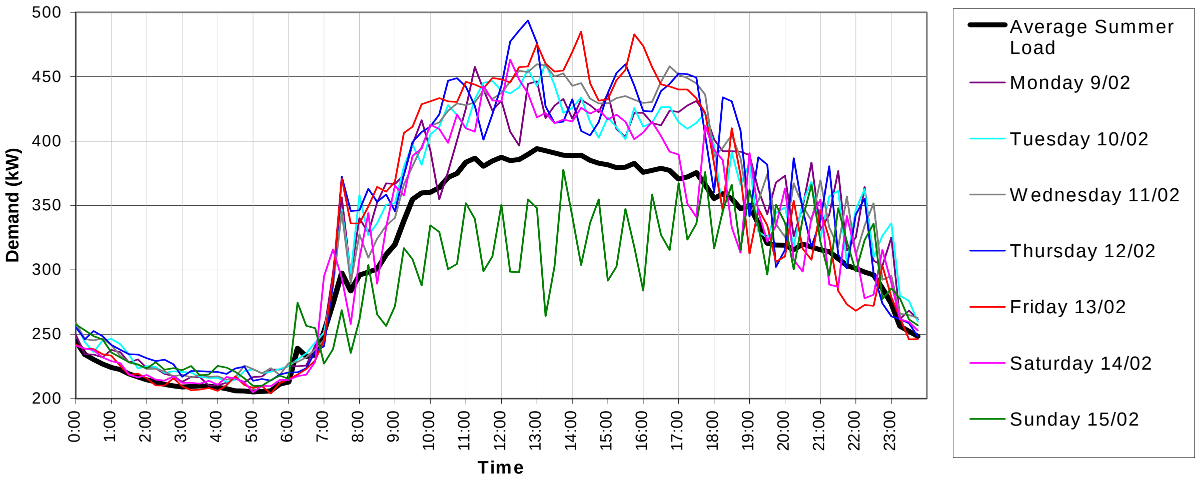
5.2 Kogarah Town Square site

The demand reduction due to the PV is the difference between the peak that would have occurred had the PV not existed and the peak that actually did occur. In this report, the peak load that would have occurred without the contribution from PV is referred to as the "*underlying*" site peak demand. The actual peak that occurred as a result of PV production is the "*resultant*" site peak demand.

5.2.1 Underlying site Demand

The period between the 6 January and 20 February was considered to represent a typical summer profile. Daily demand curves for the peak week in the period are shown in Figure 3. The bold black curve shows the average summer profile.

Figure 3: Daily demand profile of the peak week in Summer 03/04 and avearge summer profile for KTS site



The KTS site demand profile was consistent with a commercial load. The highest loads occur during work hours and Sunday load was considerably lower than workdays (Monday-Saturday). Workday load switches on at about 7am and usually peaks between 12pm and 2:30pm; although individual days reach their peak anytime between 11am and 5pm. Load drops off after 6pm and was at a minimum between midnight and 6am. Between 6am and 11pm, the site load exhibits variations of up to 50kW between 15-minute samples. This indicates a large cyclic load, probably the chiller system for the commercial and retail space. Although the site contains a significant portion of residential space, its load was small compared to the demand of the commercial space.

The site's peak demand occurred on Thursday, 12th February. The peak demand was 494kW occurring at 12:45pm. The next two highest peaks for the period both occurred on the following day, Friday, 13th February, specifically: 485kW at 2:15pm and 483kW at 3:45pm.

5.2.2 Impact of PV on KTS site

The time of peak PV output and the time of peak site load correlated well, so it was expected that reduction in peak demand would be close to the peak output of the PV. The amount of demand reduction, however, represented only 35% of the *available capacity*. Although high throughout the day, the PV production dropped in the afternoon while the underlying KTS site demand remained relatively stable until the early evening. Furthermore, the PV experienced fluctuations in demand throughout the day and so periods existed where its contribution to reducing demand was negligible. The result was that the resultant peak tends to occur later in the day and the overall demand reduction was much less than the capacity.

Figure 4: Demand Reduction due to PV production on the peak two Summer days 03/04: Thursday 12 and Friday 13 February

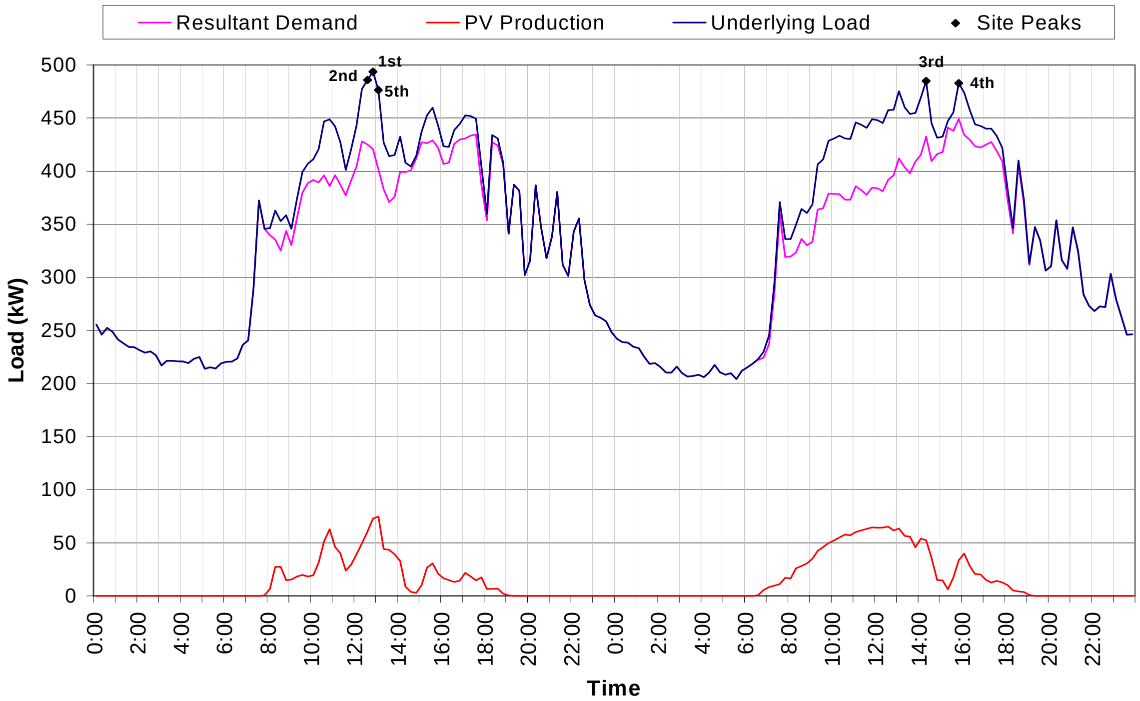


Figure 4 above shows the underlying and resultant load curves and the PV production for Thursday 12th and Friday 13th of February, which were the underlying and resultant peak days respectively. The top five 15-minute samples of site load are marked on the figure and their values are shown in the table.

Underlying Load (kW)	Peak Ranking	Resultant Load (kW)	New Peak Ranking due to PV production
494	1st	421	28th
486	2nd	425	22nd
485	3rd	432	8th
483	4th	449	1st
477	5th	428	14th

Underlying Peak: At the time of the underlying site peak, the PV was producing 73kW, which was very close to the peak output expected for the PVPS. The resultant peak for the day occurred at 5:30pm when the PV production was lower. Comparing the underlying and resultant peaks for the day, the net demand reduction was 59kW (or 56% of available capacity). Significant fluctuations were evident in the PV production during the day however they tended to coincide with periods of reduced load and so did not impact the overall demand.

Resultant Peak: The resultant peak day for the period occurred on Friday, 13 February at 3.45pm. Although the PV production on this day was very good, the demand reduction was only 34% of *available capacity*. The peak occurred in the late afternoon, when the PV output was generally lower. In addition, the PV production fluctuated at about the time of this peak and was 10kW lower than the average for that time of day. Consequently, the PV was relatively less effective at reducing peak demand on this day.

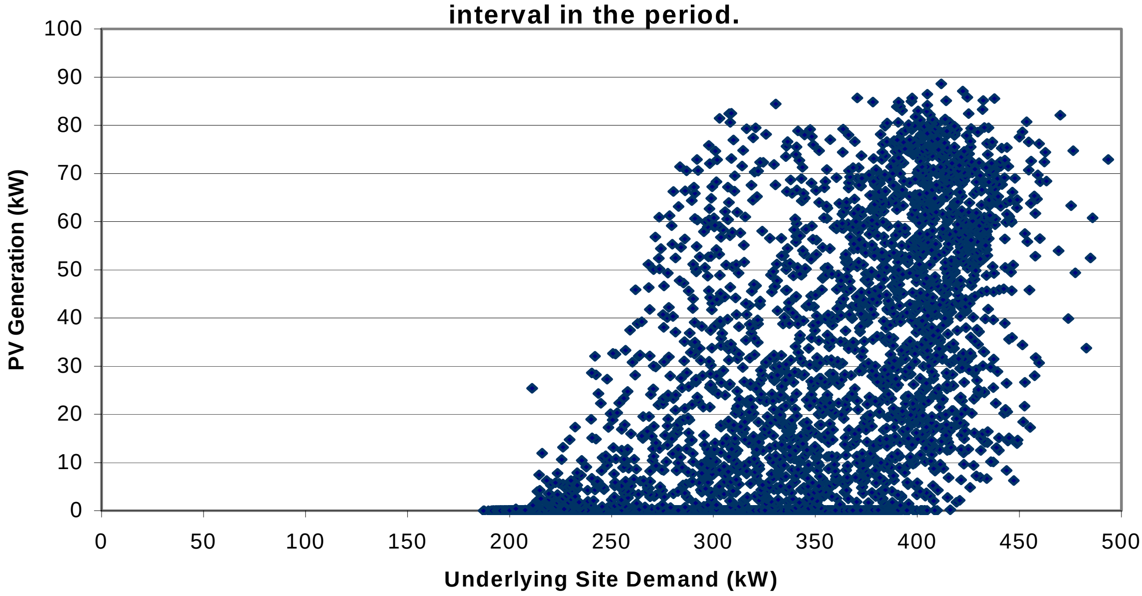
The daily resultant peak usually occurred between 5pm and 7pm. Although the underlying site peak was typically around midday, the demand was high throughout the workday until the early evening. Contrarily, PV output was lower in the afternoon. Thus, there was an increased likelihood of the network peak occurring later in the day. The average change in the time of the peak was 3½ hours.

Entire period: The difference between the actual peak over the entire period and what would have occurred without the PVPS was 45kW or 35% of *available capacity*. It is worth noting that although all potential roof area had solar panels installed, this reduction represents only 9% of the site peak demand.

5.2.3 Probabilistic Analysis

The contribution of the PV to reducing the site demand was considered relatively low. To investigate whether this level of reduction was typical of the PV, and thus to be expected in subsequent years, a probabilistic analysis of the coincidence of high site demand with PV production was undertaken. For each 15-minute interval in the period, site demand was plotted against PV generation as in Figure 5.

Figure 5: Relationship between PV Generation and Underlying Site Demand. Points represent the relationship for each 15-minute interval in the period.



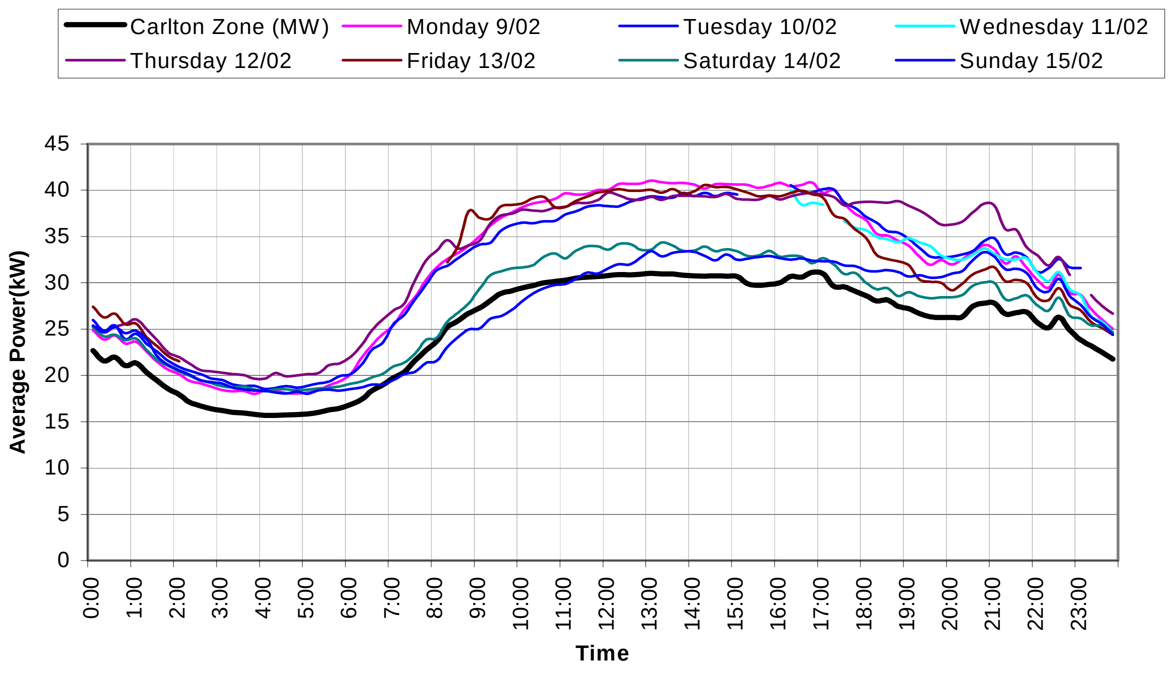
In general, there does appear to be a tendency for PV generation to be higher when site demand is higher. However, the points are widely dispersed with a large number of points for times when PV generation is low when demand is high, and conversely where generation is high and demand is low. The low level of coincidence suggests that in any period, there will be times of high demand with low PV output. Such times will determine the peak and produce demand reductions well below the peak output of the PV.

The level of the demand reduction observed is consistent with this data. On a day to day basis, the demand reduction varied greatly, from a high of 80.8kW, to a low of 3.5kW. Low levels of demand reduction are most likely to be due to daytime fluctuations in PV output since days with late afternoon peaks only represented a small proportion of days.

5.3 Carlton Zone

The local network load (at Carlton Zone substation) is predominantly commercial. Weekdays have significantly higher demand than weekends. Inspection of the peak week profile in Figure 6 shows that the load peaks between 12pm and 5pm and was quite flat across this period. On Thursday night, the high load period was extended till about 7pm, probably due to late night shopping. Several small peaks in the demand are visible between 9pm and 1am and are typically associated with off-peak hot water switching on. The peak day occurred on the 9 February at 1pm.

Figure 6: Average Zone Profiles for the Carlton Zone

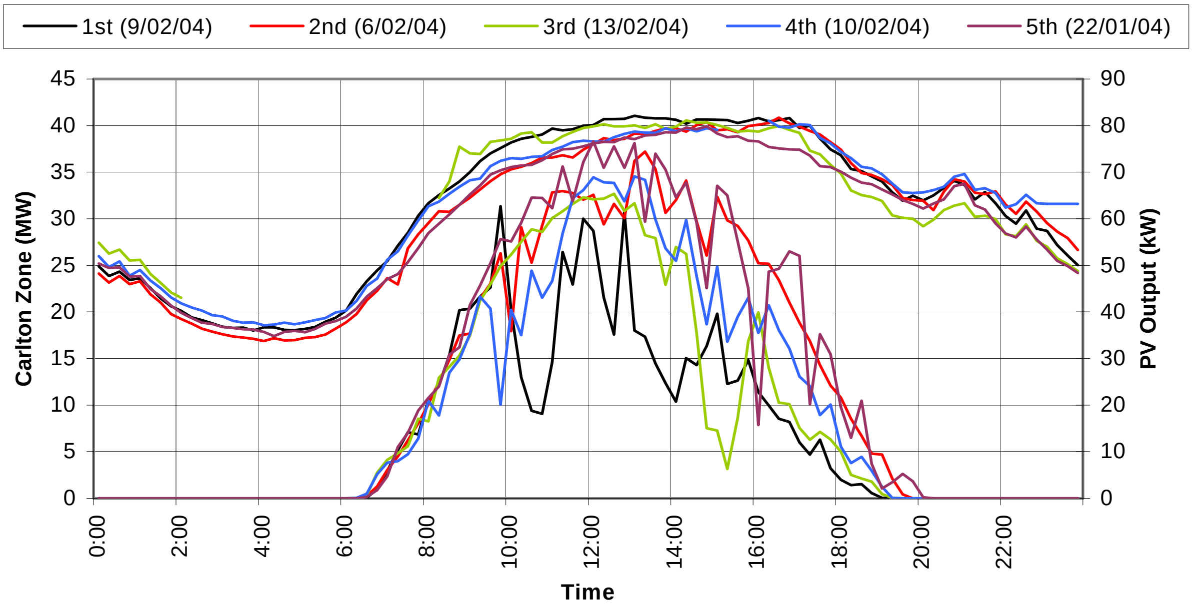


5.3.1 Impact of PV on Carlton Zone

Two main issues were observed regarding the impact of PV output on the network peak demands – consistently lower output in the afternoon/evening and random variability during peak periods. PV production and Carlton load data for peak days are shown in Figure 7. The size of the PV output is much smaller than the random fluctuation in the Carlton Zone load. Direct comparison of these disparate data sets is not informative. To mimic the effect of a larger number of similar installations, we multiplied the KTS PV production data by one hundred. On this basis, the contribution of the PV to reducing zone peak demand would be 24% of the *available capacity* of PV.

Afternoon Low Output: On the five highest network demand days, PV output had declined to an average of 40% of peak output (range 20% and 68%) for the day at 5pm. This suggests that, even with ideal performance, we could expect an impact on network demand of no more than 50% of *available capacity*. This might be improved by orientation of panels more to the west, however this would not have been a practical option in this case.

Figure 7: Carlton Zone and KTS PV data for Carlton Zone peak days



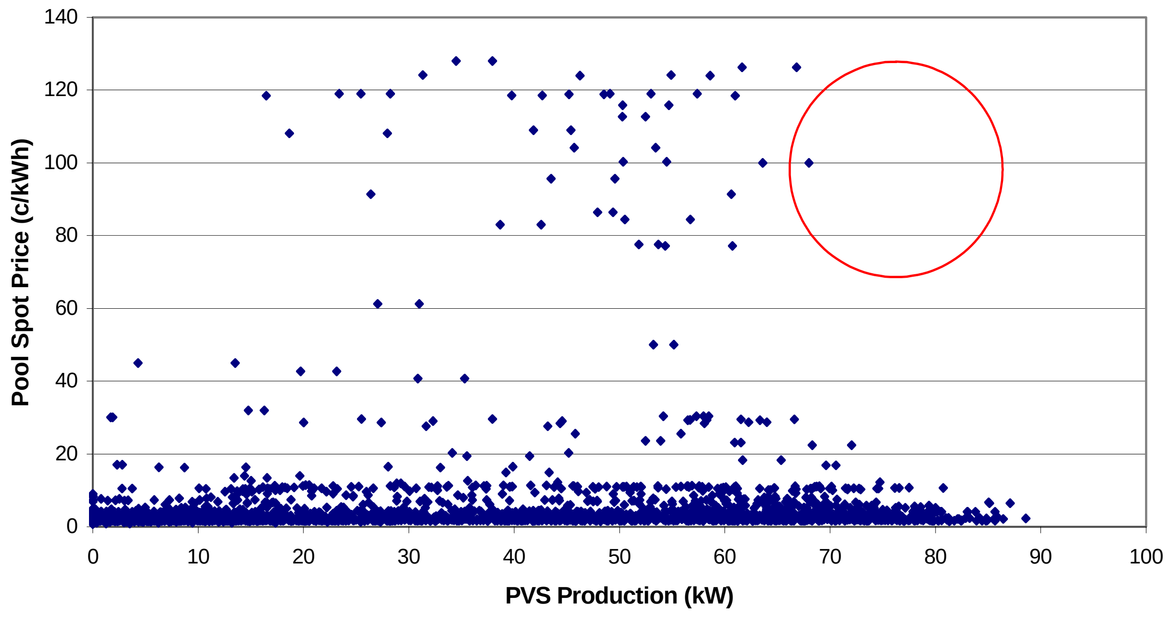
Fluctuations: On each of the five days the PV output also exhibited a large degree of random variation – even during peak output period of between 12pm and 1pm, output varied between 32% and 63% of *available capacity*. Over the critical 12pm to 5pm period, outputs as low as 12kW were observed. Since passing cloud cover seems the most likely cause of this variation; this would probably be a common mode issue for a wider, but still localised deployment of PV that would be required to enable any significant network impact.

5.4 Energy Value

In the national electricity market, energy is traded every half-hour at a 'spot price' that reflects demand and the prices bid by generators. There is a view that because PV generates power during the day when spot prices are generally higher, the average spot price would undervalue energy. To investigate this, the energy generated during the period was valued at both the average spot price and at the half-hourly spot price.

Figure 8 shows a scatter plot of PVPS production to the pool spot price for each 15-minute slot in January and February. Times of high spot price do not necessarily coincide with high PV production. Had this been the case, there would have been a concentration of points in the top right hand portion of the graph (red circled region). Instead, at times of high spot price there was a broad spread of PV outputs.

Figure 8: Relationship between PVPS Production and Pool Spot price for the studied period



The total energy produced by the PV was 21.7MWh over the period of the study. The average spot price was 4.41c/kWh, which gives a total value of $900 for this energy. Alternatively, if the energy produced in each interval were sold at the corresponding half-hourly spot price the value of the energy would have been $1,520.00, which is equivalent to an average spot price of 7c/kWh. Although this is an improvement, it is not remarkable. It should be noted that this report refers only to summer. Since summer would be expected to show the highest coincidence between high spot price and PV production, a full year analysis would be expected to show a lower weighted average price.

With bi-directional metering installed, all energy produced by the PV installation can be sold back to the grid. Most electricity retailers currently offer buyback prices around 11c/kWh, which is even higher than the pool spot price value.

6 Conclusions

There was a good correlation between the peak of the KTS site and the PVPS peak production. For the period studied, there was a reduction in demand of 45kW, or 9.1% of underlying site demand. This reduction represents 35% of available PV capacity. This relatively low contribution appears to be due to a combination of reduced PV output in the afternoon and to the wide variability in output exhibited by the PV during its peak period. Comparison of the PV profile to the local network load (Carlton Zone) suggested that a wider installation of PV would produce similar results. The typically flat load profile of the zone, if anything, would tend to exacerbate these issues.

Despite the partial coincidence between high pool prices and PVPS production, the result of the energy market analysis was that the value of the power produced by PV was lower than current market buyback tariffs. Pricing the PV at the value of the half-hourly spot price gave a value of 7c/kWh. The buyback rate commonly offered by retailers is 11c/kWh.

Several limitations of PVPS installations exist in the context of this investigation, which is primarily focused on their efficiency in reducing new network infrastructure installations by reduction of peak demand. The following issues should be considered:

- PV power production is heavily dependent on weather conditions. The amount of power produced by the PVPS at the time of the KTS peak varied widely between 3.5kW (3.2% of *available capacity*) and 80.8kW (68.1%), which corresponds to a demand reduction of 0.9% and 17.2% respectively.
- This PV installation was effective for reducing peak loads only around the middle of the day, when PV power production is at a maximum.
- Several of the inverters failed during the course of the study reducing the *available capacity* of PV output. This emphasises the need to monitor and maintain PV systems.
- Due to unpredictable nature of PVPS, the installation has much less impact on demand reduction than its nameplate rating. The reduction in peak demand for the KTS site was only 28% of the installed nameplate capacity or 35% of *available capacity*.

This study was carried out only during the summer months so four-season extrapolation cannot be performed with confidence.

Report prepared by Lianne Moller for the Demand Management Group, September 2005

Appendix A: Electrical Line Diagram