

Photovoltaic (PV) Forecast

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Photovoltaic (PV) Forecast

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1 Introduction

At this relatively early stage of Photovoltaic (PV) penetration on the Western Power Network (WPN) it is important to develop an understanding of the potential future effects of various PV generation scenarios on load demand.

This report presents the outcomes of a study regarding the impact PV generation will have on individual feeders, total system peak load demand and the annual demand profile. A major factor in determining these impacts is an understanding of the amount of system peak load demand that can be expected to be reduced, resulting from an ongoing uptake of PV's.

Increasing PV generation capacity on the network is most likely to be a result of government incentives that have reduced the effective cost of PV systems for customers. The increasing demand has encouraged competition between an increased number of suppliers, which has helped to further reduce the costs of PV systems of all sizes.

Western Power has forecast PV take-up rates (from actual data) and associated PV generation profiles (from simulated data). These were then overlaid with the system peak demand profile to determine the expected reduction in peak demand.

Western Power has also assessed the effect of varying levels of PV system penetration on peak load demand, including changes in characteristic daily and yearly load profiles for different customer classes.

Since actual PV generation data was not available at time of compiling the report, simulated data has been used. In the next annual update of this report, actual PV generation data will be readily available for analysis.

2 Assumptions and methodology

2.1 PV generation forecasting

2.1.1 Forecasting installed PV generation capacity

Number of Systems

The current PV generation capacity of 47,153 PV system installations is based on approved applications to the end of January 2011. Between September 2010 and January 2011 there was a strong growth in approved applications to around 3,000 PV systems per month. Prior to this, the take-up rate was around 2,000 PV systems per month.

It is expected that as government subsidies for PV systems are reduced over time, take-up rates will return to the longer term rate of 2,000 PV systems per month.

Three different PV system take-up forecasts are considered in this report:

- Forecast 1: 2,000 PV systems per month
 - Based on the longer term take up rate;
- Forecast 2: 3,000 PV systems per month
 - Based on the more recent higher take up rate;
- Forecast 3: 1,000 PV systems per month.
 - Based on a reduced and moderate take up rate;

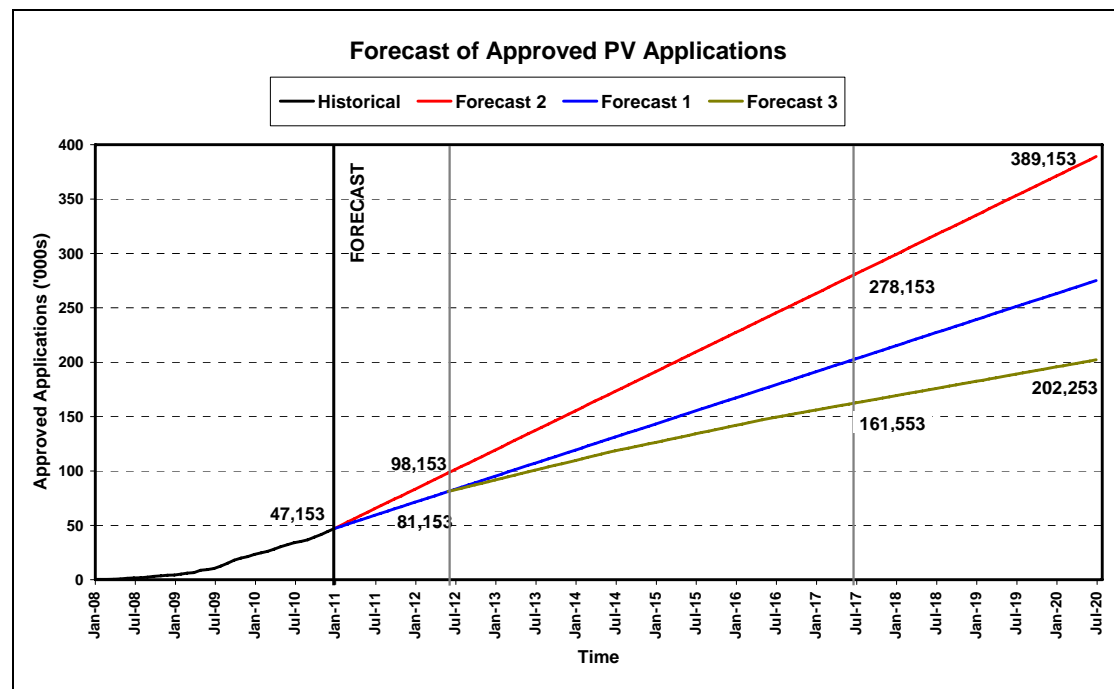


Figure 1: Forecast of approved PV applications

Average size of systems

Another trend that is evident from applications received is that the average PV system size has been steadily increasing:

- May 2009:
 - Average 1.2 kW System based on Australian Greenhouse Office (AGO) data for the Solar Homes And Communities Plan (SHCP);
- May 2009 – June 2010:
 - Average 1.5 kW System based on Office of Energy (OoE) information;
- June 2010 – present:
 - Average 1.8 kW System based on info provided on Net Feed-In Tariff;

It is not likely that this trend will change in the immediate future; particularly as the retail price of PV systems are expected to continue to reduce. In this review the size of the PV systems has been capped at 3kW which is expected to be a limiting factor given the current size and capacity of solar panels and the available roof area on a standard Perth home.

The Total PV generation forecast is calculated using the equation below.

PV generation forecast
=
(Number of PV systems) × (Average PV system size)

Equation 1: PV generation equation

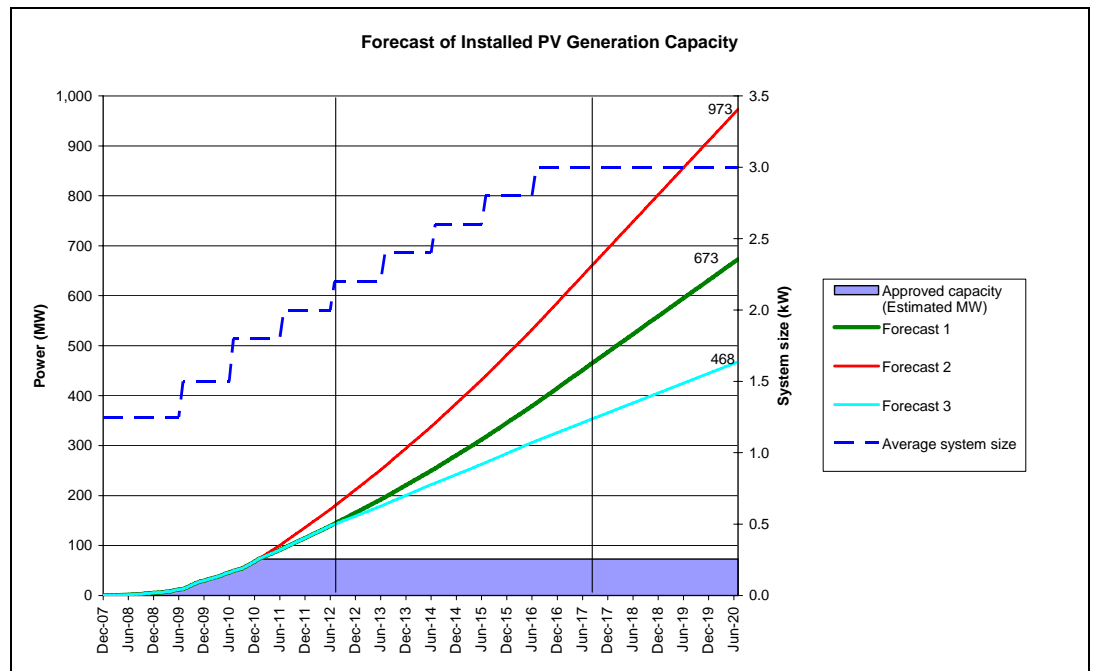


Figure 2: Forecast of installed PV generation capacity

2.1.2 PV generation output capacity

The PV generation profile has been prepared using simulated data from the National Renewable Energy Laboratory's (NREL) PV Watts Calculator for each hour of the year. The NREL calculator uses a yearly set of data derived from each calendar month from a different year during the period 1983 to 1999.

The NREL PV Watts Calculator can be used to estimate the power output of grid connected PV systems anywhere in the world. This allows a user to develop an estimate of the performance of hypothetical PV installations.

The PV Watts Yearly Hourly Performance Data Output calculator uses typical hourly meteorological weather data over a year and a PV performance model to estimate annual power output for a crystalline silicon PV system.

In this analysis, and under the adopted criteria:

- PV systems are installed at 22.6 degrees to the horizontal, which is the average roof angle for the Perth metro area
- the orientation of the PV systems is assumed to be evenly distributed about the mean of North (0 degrees) with a standard deviation of 60 degrees. For maximum PV output, the PV systems are assumed to be orientated from West to North, to East

Figure 3: Daily PV generation, showing the hourly PV generation profiles for the following case studies of **daily** PV generation profiles, includes:

- high case (average output values experienced during summer);
- mid case (average output values experienced over the year);
- low case (average output values experienced during winter);

These profiles use the sunlight intensity at the end of each hourly period; hence Figure 3: Daily PV generation, shows generation output at the end of each hour.

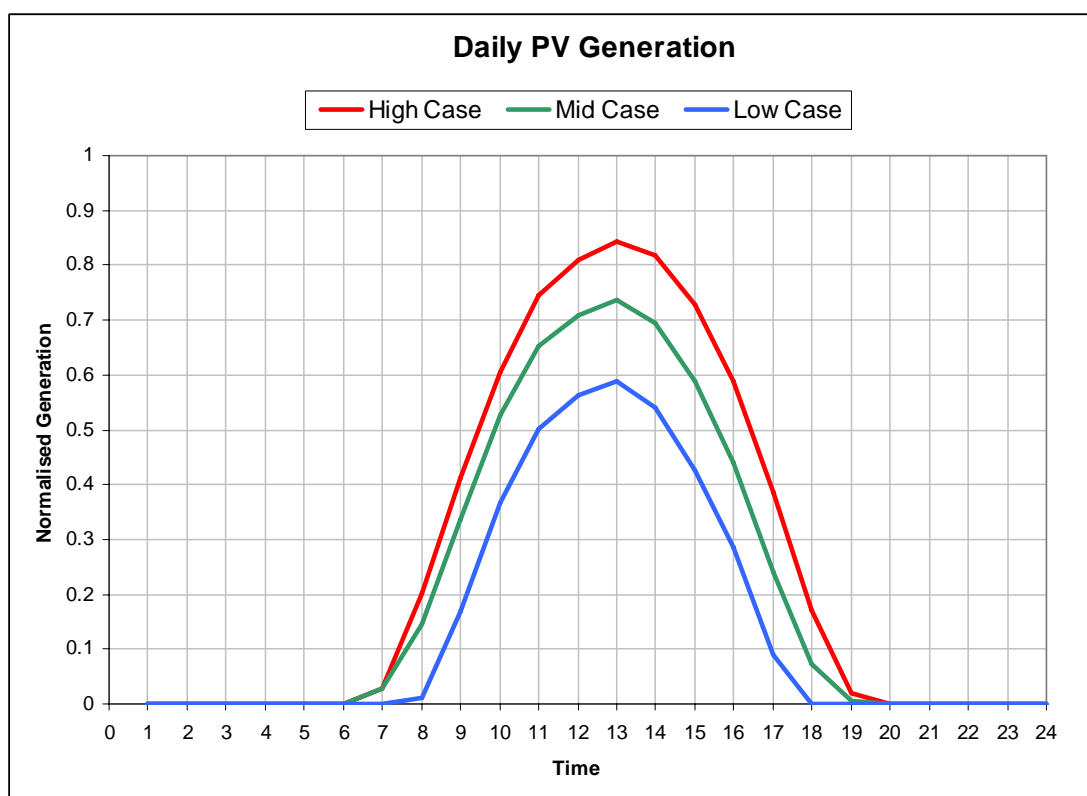


Figure 3: Daily PV generation average output capacity per PV unit

2.2 The impact of PV systems

The impact of PV Systems is examined by its effect on the following demand profiles:

- Typical SWIS feeder profiles
- SWIS peak demand day
- SWIS over an entire year

2.2.1 Impact of PV Systems on typical feeders

In the WPN, the following six (6) normalised daily feeder profiles have been identified:

1. Residential (Feeders with primarily residential loads);
2. Commercial (Feeders with primarily commercial loads);
3. Industrial (Feeders with primarily industrial loads);
4. Heavy Industrial (Feeders with primarily HV loads);
5. Mixed (Feeders which are not dominated by any particular customer type, but display a large mix of residential, commercial, industrial and HV customers);
6. Other (Feeders which do not fall into any of the above categories and typically have dedicated customers assigned to them);

The impact of PV generation on a feeder is directly related to the level of PV penetration on the feeder. For the purposes of this document, PV Penetration is defined as the ratio of installed PV capacity, to the percentage of the peak load demand.

$$\text{PV Penetration} = \frac{\text{Installed PV system Capacity}}{\% \text{ Maximum System Load}}$$

Equation 2: PV penetration equation

The impact of PV systems on feeder loads is dependent on PV penetration levels and the feeder's load profile, less the product of normalised PV Generation and PV Penetration.

$$\begin{array}{c} \text{Effect of PV systems on feeders} \\ = \\ \text{Feeder load profile} \\ - \\ \text{(Normalised PV generation} \times \text{PV penetration)} \end{array}$$

Equation 3: Effect of PV systems on feeders

2.2.2 Impact of PV on the WPN peak day

The 2010 WPN System Forecast shows the anticipated total peak load demand profile to 2017 and beyond. It includes the effect of existing PV's embedded in the network as at February 2010, but does not take into account the forecast expansion of additional PVs in the WPN.

The average PV generation profile for the 10 days with the highest PV output is assumed to be co-incident with the WPN peak load demand day in summer. This is because most of the summer peak demand values in the WPN occur on bright clear summer days which provide high PV outputs.

The total customer demand is the sum of the measured SWIS load demand profile, and the average maximum 10 day PV generation that is expected to occur at the time of system peak demand.

$$\begin{array}{c} \text{Total customer demand} \\ = \\ \text{SWIS load demand profile} \\ + \\ \text{PV generation output} \end{array}$$

Equation 4: Total customer demand

The forecast increase in PV systems at customer premises is likely to effectively decrease the current WPN System Forecast by the quantity modelled in this study. This impact will be taken into account in the 2011 WPN Summer Forecast.

2.2.3 Impact of PV on the WPN (entire year forecast)

For this analysis the entire 2010 hourly demand profile, of total customer load, is shown with the effect of PV generation as well as without the effect of PV generation. This 2010 profile is then grown by the current forecast yearly growth rates for each year in the AA3 period. In addition, the forecast PV generation is added to the yearly profiles between 2012 and 2017, to depict the impact of PV generation on the total customer load.

3 Results and analysis

3.1 Indicative impact of PV generation on typical feeder types

3.1.1 Introduction

Western Power's System Forecasting has categorised feeders into a number of general groupings:

- residential feeders
- commercial feeders
- industrial feeders
- mixed feeders
- HV feeders
- other feeders

For each grouping, normalised daily load profiles have been determined using historical load data over a number of peak days for all feeders.

As the feeder profiles are normalised averages; as opposed to a specific feeder peak load demand and generation capacity, it is not possible to forecast and apply a specific level of PV penetration. As stated in section 2.2.1, PV penetration has been defined as the ratio of installed PV (rated) capacity for the feeder, to the percentage of the feeder peak.

Using the high, mid and low PV generation curves, the load demand profiles for each feeder type have been adjusted for varying levels of PV penetration rates.

Results were calculated using 10 per cent intervals in PV penetration ranging from 10 per cent to 100 per cent.

The results below are determined for the summer period when the contribution from PV systems is at, or near, the maximum available generation. The time of the peak load of the various feeder types will significantly impact on the benefit that PV systems have as decreasing light capacity will greatly affect PV generation levels.

3.1.2 Feeder profiles - comparing load with and without, PV generation.

3.1.2.1 Comparison of various feeder types at 10 per cent PV penetration

Shown below are typical daily profiles for the six general feeder types identified by system forecasting. These profiles have been adjusted for the expected effects of PV penetration of 10 per cent of the feeder peak, for high, mid and low PV generation levels.

The charts included here are intended to provide a visual comparison of the effects of PV on each feeder type.

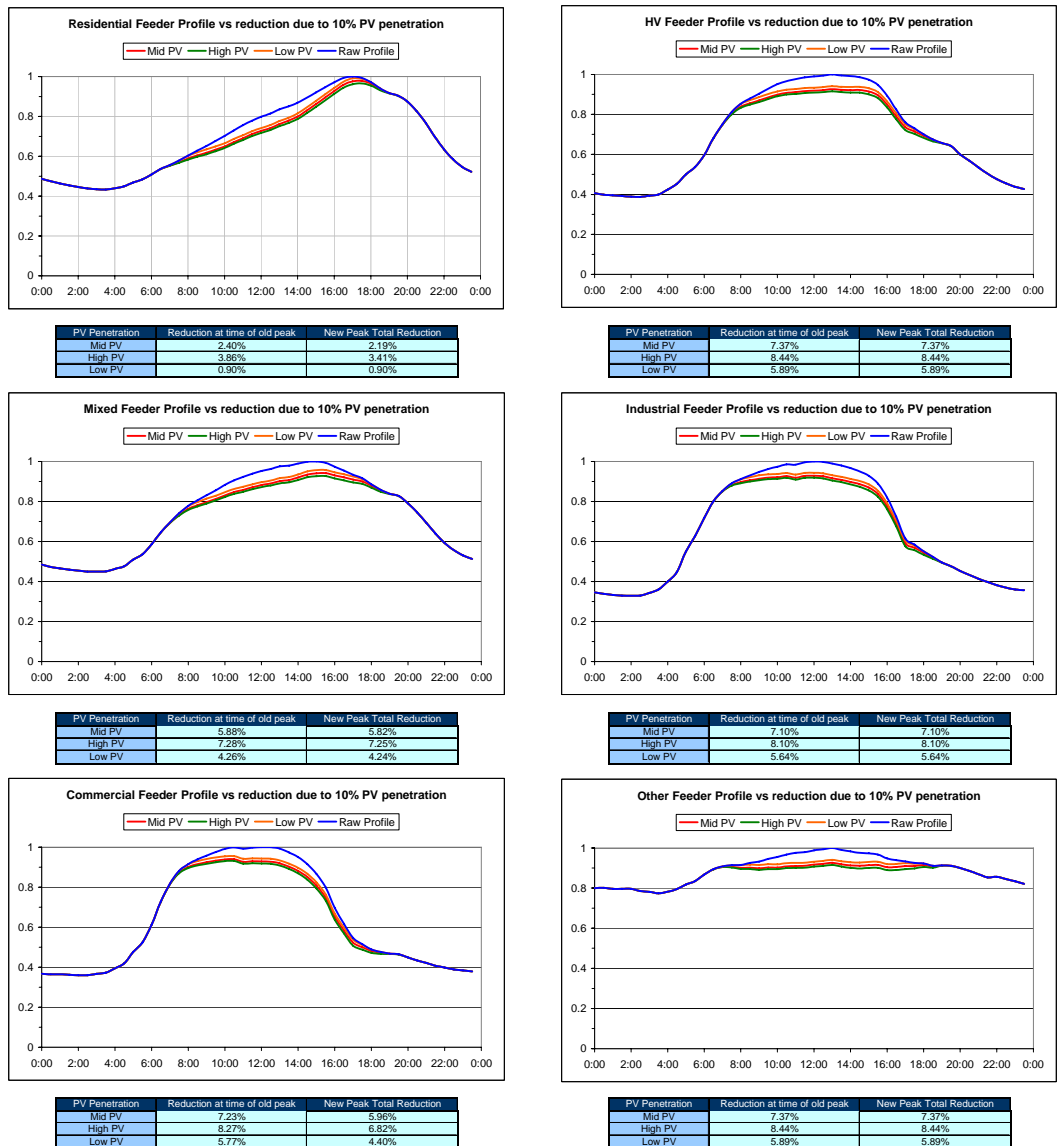


Figure 4: Comparison of average feeder loads by load profile at 10 per cent PV penetration.

From examination of the various profiles, it is apparent that the effectiveness of PV at reducing the peak differs significantly for different feeder types. In particular, the residential feeder peaks at 6:00pm and maintains a relatively high load demand until 8:00pm, and consequently exhibits a significantly smaller reduction in peak when compared with the other feeder types.

3.1.2.2 Residential feeder at various PV penetration percentages

The majority of individual PV installations involve residential customers. Therefore particular attention is given to the effect of PV on a residential feeder. It can be seen from the results shown in section 3.1.2.1 that due to the shape of the profile, the reduction in peak for a residential feeder is significantly less than for other feeder types at the same PV penetration.

Shown below is the effect of PV on a residential feeder at 10 per cent, 20 per cent, 50 per cent and 100 per cent PV penetration:

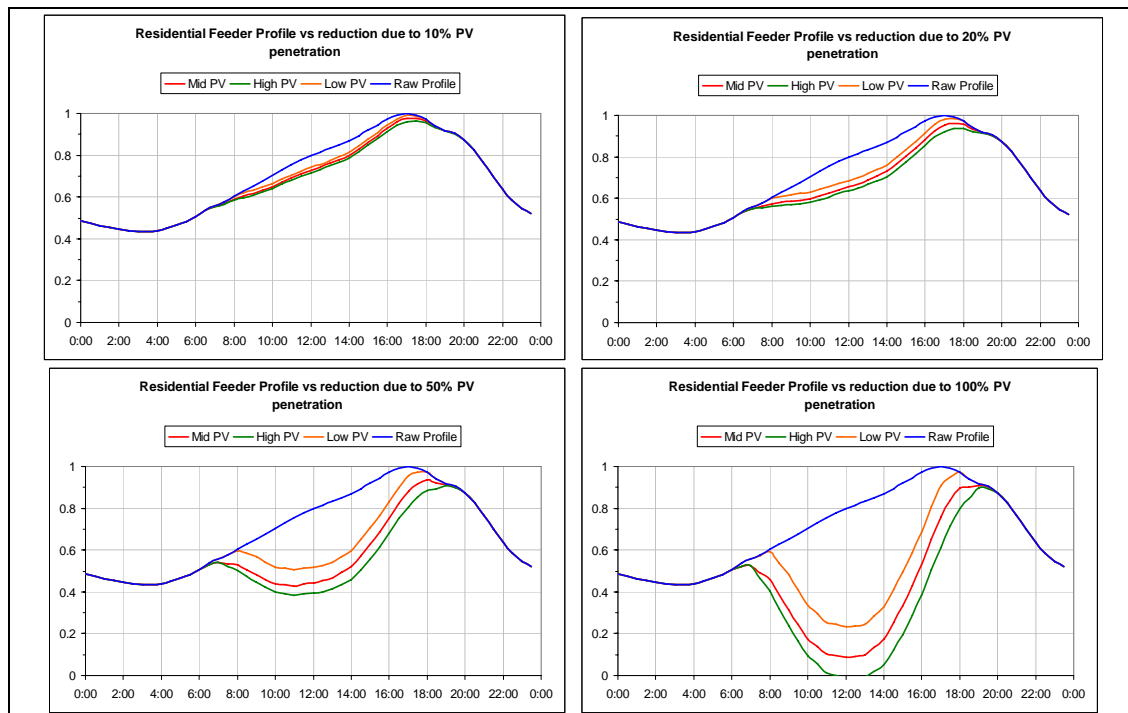


Figure 5: Residential feeder average loads at various PV penetration levels.

From the observation of these results, two conclusions may be drawn:

1. Even at increased PV penetration, the reduction in peak is small for a residential feeder (~10% peak reduction at 100% PV penetration). In fact, there appears to be minimal reduction in peak by increasing PV penetration from 50% to 100%;
2. In summer, higher PV penetrations tend to reduce the residential load demand between 10:00am and 2:00pm, and may reduce the maximum demand in the hour to 8:00pm, to 90% of the feeder demand without PVs. This may present

other issues for the daily operation and management of the power system;

3.1.2.3 Reduction of peak for various feeder types

Shown below is a summary of the peak reduction for each combination of feeder type and percentage PV penetration

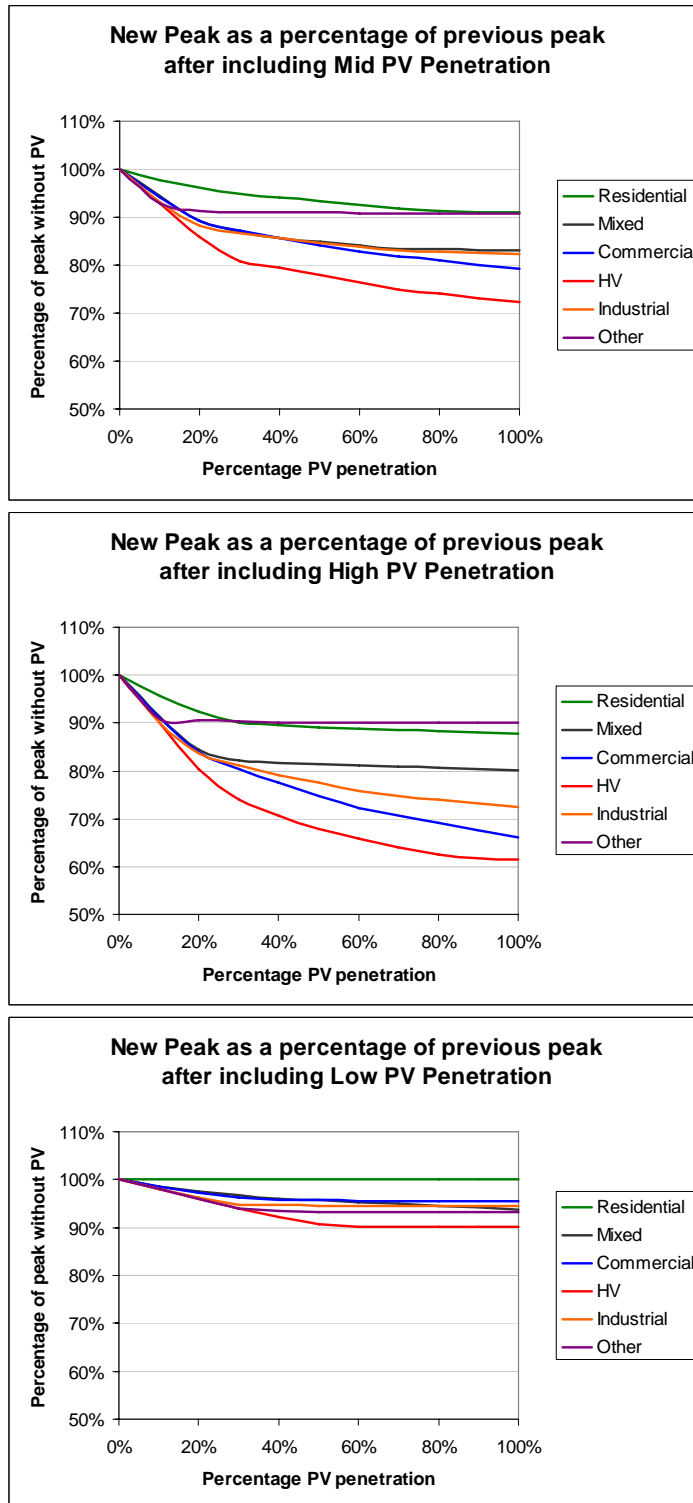


Figure 6: Effect of PV penetration on peak load.

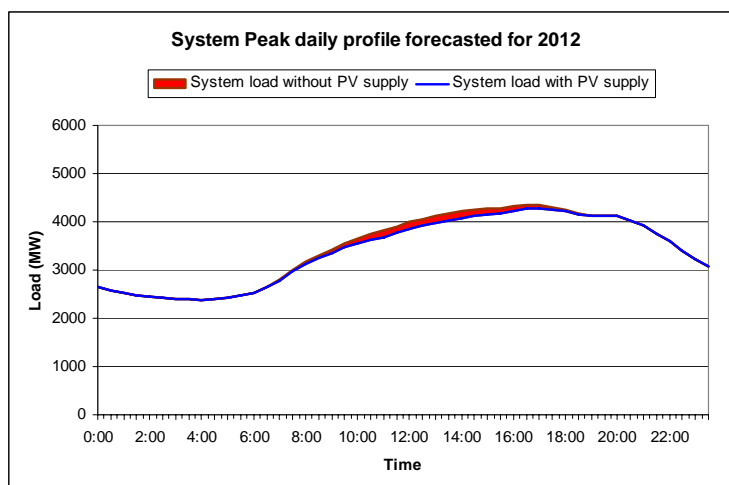
From examination of these results it is apparent that for all feeder types; but particularly residential and mixed feeders, any further reduction in peak becomes increasingly small at higher percentages of penetration; minimising the benefit (from the perspective of peak load reduction).

3.2 2012-2017 forecast of the effect of PV on the WPN Summer Peak Day

This section summarises the key results of a forecast with and without PV generation, for the peak load demand day on the WPN over the AA3 period.

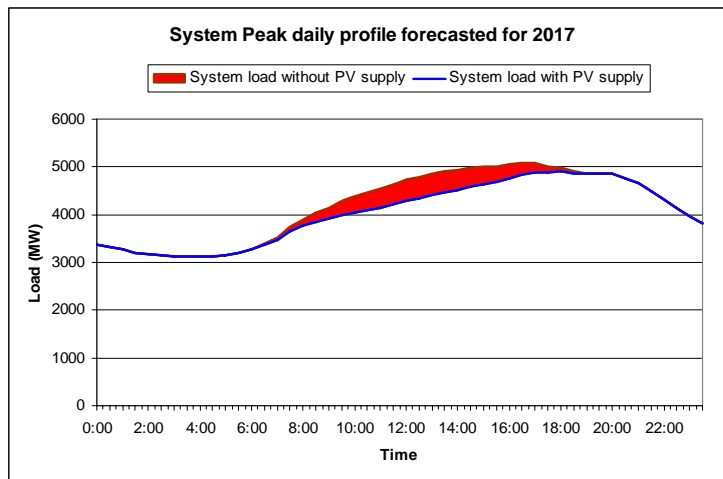
3.2.1 Graphical comparison of the reduction in load due to forecasted PV generation for the peak load demand day from 2012 to 2017

Shown below are comparison load demand profiles for the total WPN; with and without forecasted PV generation, as forecasted for 2012 and 2017. For this analysis the 2010 peak summer day profile has been used as the base profile for the forecast period. The 2010 profile was uniformly grown for each subsequent year and the forecast PV penetration rate of 2,000 applications per month, are applied to each annual profile to determine the expected impact of PV generation.



Percentage of Maximum PV contribution (not at peak)	3.51%
Percentage reduction of peak load on network	1.50%

Figure 7: Expected change in system load due to PV penetration in 2012.



Percentage of Maximum PV contribution (not at peak)	9.21%
Percentage reduction of peak load on network	3.53%

Figure 8: Expected change in system load due to PV penetration in 2017.

3.2.2 Tabulated results and analysis – summer period

Shown below are results summarising key effects of the PV on the WPN peak load demand day profile

Year	PV Penetration at System Peak Load Demand(PV Generation at System Peak Load Demand		Actual Peak Reduction	Maximum % load supplied by PV
	MW	% of Peak Load	MW	% of Peak Load		
2012	148	3.40%	76.3	1.75%	1.50%	3.51%
2013	207	4.56%	106.8	2.35%	1.95%	4.67%
2014	263	5.64%	135.6	2.90%	2.38%	5.77%
2015	324	6.70%	166.9	3.45%	2.80%	6.83%
2016	390	7.86%	200.7	4.05%	3.26%	8.01%
2017	460	9.06%	237.0	4.67%	3.53%	9.21%

Table 1: Contribution of PV generation to supply system peak load.

- *PV penetration at system peak load demand* is included to provide a comparison with the penetration percentages used in modelling the effect of PV on feeders (as calculated in section 3.1)
- *PV generation at system peak load demand* indicates the PV generation present at the time of maximum customer load demand, assuming no PV generation is present. Please note that this is different to the peak load demand of the feeder if PV generation is present
- *Actual peak reduction* indicates the difference between the system peak load demand with and without PV generation
- *Maximum % load supplied by PV* indicates the time at which PV generation has the maximum impact on the total load demand

One observation from these results is that despite a fairly constant increase in PV generation, the additional peak reduction decreases each year. This is demonstrated by the graph below

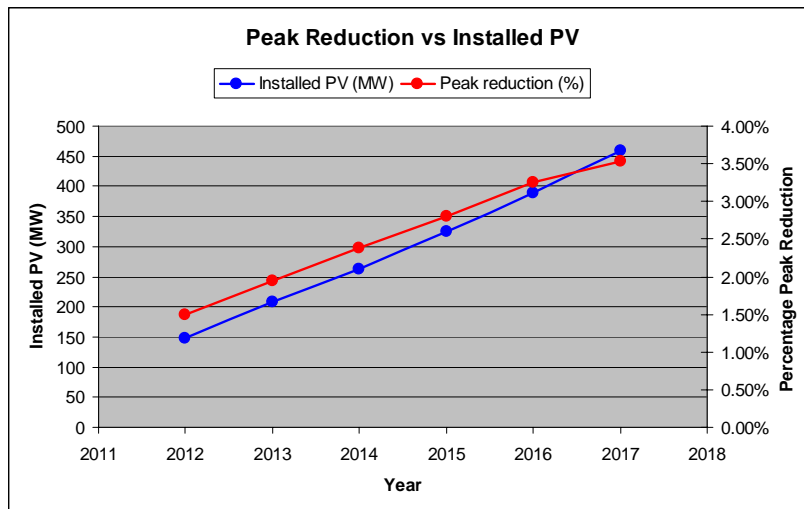


Figure 9: Peak reduction verses installed PVs.

In a summer period, this is consistent with the results observed for the feeder profiles and upon further examination of the 2017 profile curves, it is apparent that the peak is only slightly higher than the load demand at 8:00pm; when PV generation is effectively zero. Therefore, it is expected from these forecasts that by 2017, increased PV penetration will have minimal effect on the reduction of the peak load for the WPN. However, increased PV penetration will result in a higher maximum percentage of load being supplied by PV during a non-peak time; which may present other issues for the daily operation and management of the power system.

3.3 2012-2017 Daily Forecast for the Yearly Effect of PV on the WPN

This section summarises the results of a forecast; with and without forecast PV generation for the WPN over a full year for the period 2012 - 2017. This forecast uses the 2010 historical hourly load demand profile for the WPN to examine the effect of PV generation. The 2010 profile is uniformly grown for each subsequent year and the forecast PV penetration rate of 2,000 applications per month, are applied to each annual profile to determine the expected impact of PV generation.

3.3.1 Graphical comparison of the reduction in load due to forecasted PV generation for 2012 and 2017

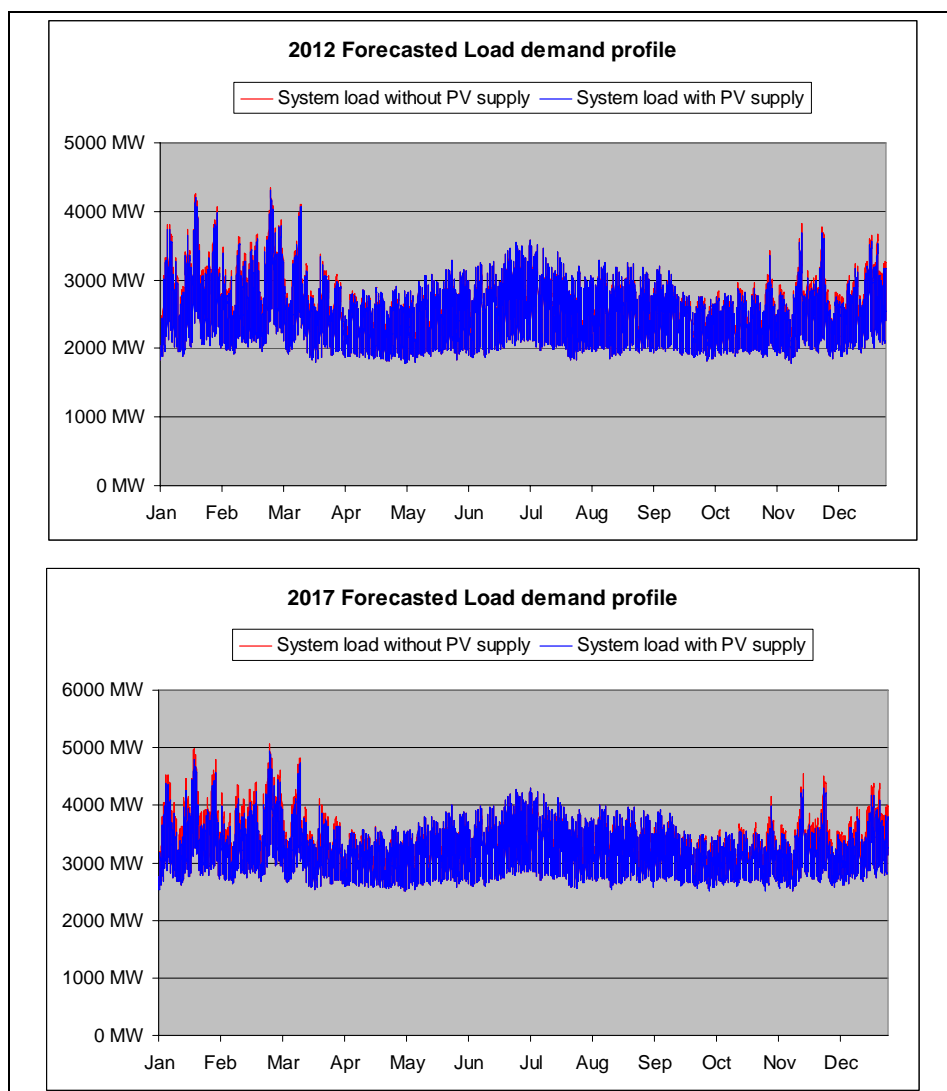


Figure 10: Effect of PV generation on the SWIS from 2010 to 2017.

Proportionally, there is little difference observed between the 2012 and 2017 profiles. It is also apparent that the impact of PV generation during winter months is negligible when compared to the size of the load demand.

3.3.2 Load factor and Load Duration Curve comparisons

The load factor and load duration curves are based on the most recent year (2010) where PVs have started to have an impact on network load characteristics. For future years the increasing penetration of PV systems is based on Office of Renewable Energy Regulator data.

	2010 peak load	2010 Average Load	2010 load factor
With PV generation	4007.76 MW	2204.62 MW	0.550
Without PV generation	4017.50 MW	2214.39 MW	0.551

Table 2: Effect of PVs on Load Factor in 2010.

These results demonstrate a marginal decrease in load factor with PV generation.

A comparison of the load duration curve; with and without PV generation, is included below

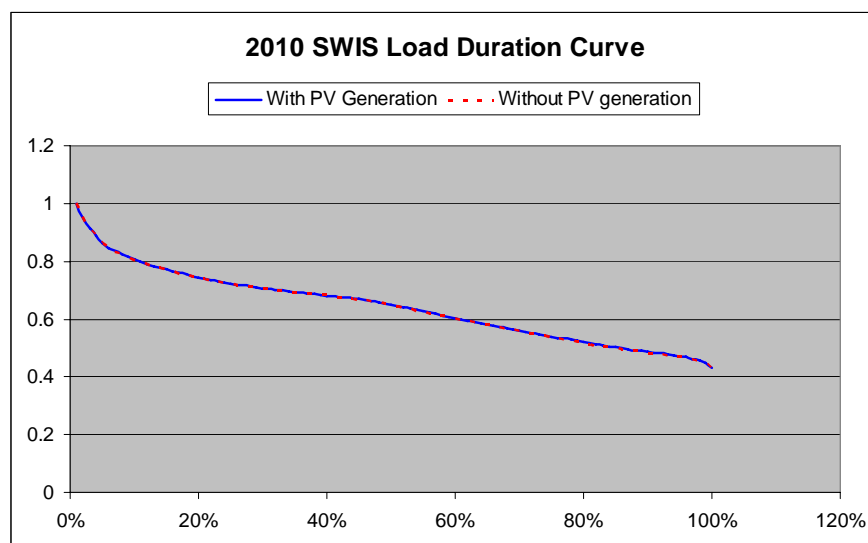


Figure 11: Effect of PVs on Load Duration in 2010.

It is apparent that at 2010 levels of PV penetration, any changes to the load duration curve are minimal.

Shown below, as an indicative estimate, future load factors were produced by reducing the 2010 load demand by the PV generation forecasted for the AA3 period

Year	Load factor with PV generation
2012	0.548
2013	0.547
2014	0.547
2015	0.546
2016	0.545
2017	0.544

Table 3: Forecast Load Factors with forecasted PV generation capacity.

It is apparent that the increased PV generation has a marginal effect on load factor.

3.3.3 Energy forecast

Shown below is an energy forecast for the entire SWIS over the AA3 period indicating the percentage of energy supplied by the forecast PV generation.

Year	Total Energy demand (GWhr)	Energy supplied by PV	
		MWhr	%
2012	22240.73	316.15 MW	1.42%
2013	23980.59	422.96 MW	1.76%
2014	25058.42	531.59 MW	2.12%
2015	26528.46	649.30 MW	2.45%
2016	27568.24	776.09 MW	2.82%
2017	28622.73	910.83 MW	3.18%

Table 4: Forecasted Total energy demand and Energy supplied by PV

Comparing the Actual Peak Reduction in Table 1, to the % Energy Supplied by PV in Table 4, it is evident that the energy supplied by PV is fairly similar to the amount of reduced peak demand; hence the reason why load factors with PV generation remain fairly constant.

4 Conclusion

At the feeder level, it is apparent that for all feeder types, an increase in PV penetration results in varying peak load reduction, with a particularly small peak load reduction for residential feeders.

In summer, residential feeder peaks can possibly be reduced by up to 10 per cent and the peak time shifted by up to 90 minutes later. In winter, residential feeder peaks and times are not changed.

In summer, mixed use feeder peaks can possibly be reduced by up to 10 per cent, but there is no change in the time of the peak.

In winter, for all feeder types the capacity to reduce peak load is significantly decreased due to the lower light capacity and length of effective daylight hours.

In summer, the higher capacity and contribution of PV generation to supply customer loads in particular market segments may present issues for the daily operation and management of the power system.

4.1.1 Improvements to this forecast

- This forecast should be reviewed when actual PV generation values are available for the WPN
- To improve accuracy, the data should be retrieved in much smaller time intervals, e.g. five minutes

In addition, the 2011 Summer Peak Load Forecast should take into account the impact of PV generation on peak load demand as determined in this study.