# EVALUATING THE BENEFITS OF IMPLEMENTING EXISTING STORAGE TECHNOLOGIES WITH RESIDENTIAL PV ROOFTOP SYSTEMS

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ABSTRACT: PV rooftop systems can produce a significant proportion of daily household needs, yet that relies on the careful design of the system and the time of energy use. With reducing FiT (feed-in-tariff) values (IPART, 2012a) and Federal supports across Australia, it makes little sense to install larger PV (Photovoltaic) systems on residential rooftops, where most of the electricity generated would be exported directly to the grid.
This study aims to study the benefits, both financial and technological, of adding storage to existing rooftop distributed PV systems for residential households in Sydney, Australia. A mathematical model was constructed to analyse and manipulate the available data. It was concluded that addition of storage resulted in a significant reduction in the peak hour energy consumption; hence alleviating the need for expensive network upgrades, while increasing financial returns from the renewable energy system, from an end user point of view. Significant reductions in return-on-investment and increase in yearly financial savings were observed.
Keywords: Self-Consumption, Storage, Rooftop, Demand Side, Economic Analysis

## 1 INTRODUCTION

In Sydney, it was observed that most residential working consumers use most of their electric power during the evening hours of 5pm to 10pm on weekdays. Installing solar systems on these households has little or no value for the customer as most of the electric power generated is exported to the electricity grid for a small FiT. Peak hour electricity tariffs apply approximately from 2 pm to 8 pm (Origin Energy), showing that most consumers pay peak tariffs for much of their consumption. This also leads to increased demand in the peak hours from the electricity network, requiring expensive network upgrades. The electricity distribution system of Australia reaches the limits of its capacity during the peak hour loads (Transmission & Development, 2012). One potential solution for effectively utilizing the generated solar energy is the implementation of distributed storage systems.

This research aims to study the benefits, both financial and technological, of adding storage to existing rooftop distributed PV systems on residential households in Sydney, Australia and estimate the required amount of storage for a given PV system size for a typical household, to make more financial sense and make PV a major and more dispatchable electricity source.
The study also analyses the impact of installing storage in customer households on evening peak electricity load.

The end user data for residential households and network load data for Sydney, Australia were examined and the impact of the type and size of a storage system on electricity consumption and network load are quantified. A mathematical model was constructed to analyse and manipulate the available data.

## 2 MODELLING METHODOLOGY

For the analysis, actual customer load data was obtained for a selection of Sydney households. The households were theoretically installed with PV systems of different capacities and the output of the system was modelled using Bureau of Meteorology one-minute solar data. A study of the financial benefits of PV systems under different regimes and the impact of the system on the total network load was modelled. Storage systems of different sizes were then added in to the systems to store the excessive PV power generated during the day, for use during the evening peak time. A study of the financial benefits and effective network load was again performed on the new system and compared to the base case.

Some of basic assumptions made in the model have been presented in Table 1 to Table 4.

An analysis was performed for customers under a time of use tariff regime with significantly high peak time prices. Table 1 presents the electricity prices for Origin Energy.

Table 1: Sydney Electricity Tariff Structure (Origin Energy – From 1 July 2012)

| Tariff Structure | Day | Time | Electricity Prices (Ac/kWh) |
|---|---|---|---|
| Time of Use Structure | Weekdays | 7am to 2pm | 21.34 |
| | | 2pm to 8pm | 52.54 |
| | | 8pm to 10pm | 21.34 |
| | | 10pm to 7am | 13.09 |
| | Weekends | 7am to 10pm | 21.34 |
| | | 10pm to 7am | 13.09 |
| Standard Structure (AEMC, 2013) | All Days | All Times | 33.44 |

Lead Acid batteries of different capacities were installed to study their impact on system payback times. The specifications of the batteries have been provided in Table 2. The modeled cost of solar rooftop systems is presented in Table 3.

Table 2: Battery system specifications (Alco Battery, 2012)

| Battery Size | System Voltage | Installed Capacity | Costs (A$) |
|---|---|---|---|
| 287 Ah | 24v | 6.8 kWh | 2,648 |
| 359 Ah | 24v | 8.6 kWh | 3,190 |
| 600 Ah | 24v | 14.4 kWh | 3,748 |
| 750 Ah | 24v | 18 kWh | 4,395 |
| 900 Ah | 24v | 21.6 kWh | 5,121 |
| 1380 Ah | 24v | 33.1 kWh | 6,560 |

Table 3: PV System Costs (Solar Choice, 2012)

| System Size | Installed Costs (A$) |
|---|---|
| 1.5 kWp | 2,716 |
| 2 kWp | 3,872 |
| 3 kWp | 5,673 |
| 4 kWp | 7,520 |
| 5 kWp | 9,004 |

## 3 PV GENERATION & LOAD DATA

A MATLAB model was developed to estimate the PV system output. The 1-minute solar data (Bureau of Meterology, 2012) was converted to half hour data to match with the corresponding Load data obtained for 10 customers on the Endeavour Energy Networks. The PV system output was derated to appropriate values to obtain a realistic output. A comparative chart was plotted to show annual consumption vs. estimated annual bill for both standard and ToU tariff for 10 customers.

It can be observed (Figure 1) that customer 2, 3 and 8 have fairly high electricity consumption when compared to other customers and also the average NSW household consumption. Since in this research, analysis for individual customers is presented, this load variation provides a good diverse data set.

It is interesting to note that according to the model, under the assumed standard tariff regime, residential customers end up paying more for their consumption. This is justified, as their consumption is higher in the shoulder period than in peak period of ToU tariff.

Table 4 presents the modelled average daily output values of the PV system in both summer and winter months. Yearly average has also been computed for Sydney.

Table 4: Average daily generation

| System Size (kWp) | Model Values (Daily Output) | | |
|---|---|---|---|
| | Average summer (kWh) | Average Winter (kWh) | Average Yearly (kWh) |
| 1.5 kWp | 7.60 | 3.59 | 5.59 |
| 2 kWp | 10.13 | 4.78 | 7.45 |
| 3 kWp | 15.77 | 7.45 | 11.61 |
| 4 kWp | 21.03 | 9.93 | 15.48 |
| 5 kWp | 26.29 | 12.41 | 19.35 |

The PV output data and customer load for summer and winter months are plotted in Figure 2 and Figure 3 respectively. A large variation in the peak consumption time and peak generation time can be seen, especially in the winter months. Annual average profiles are presented in Figure 4.

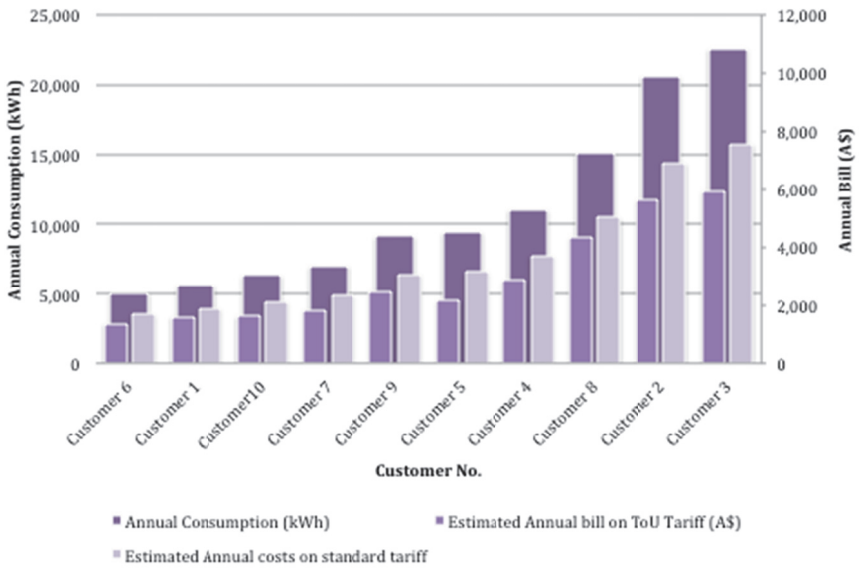


Figure 1: Customer Energy usage comparison

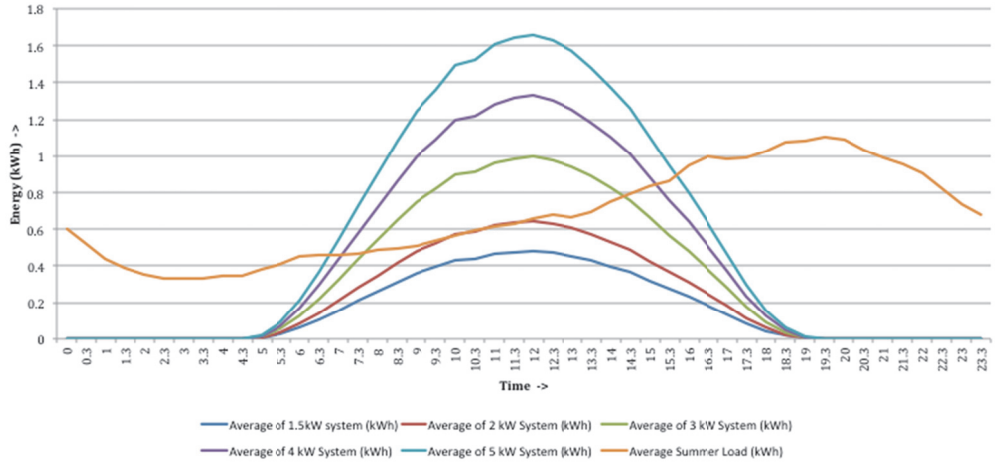


Figure 2: Average PV Generation and Load profile curve for Sydney summer

The summer load profile is flatter and the peak load is less prominent.
Also the PV systems larger than 2kWp largely export their power to the grid during the day. IPART estimates that the average system size in Sydney is around 2.3kWp (IPART, 2012b) and so it can be said that much of the power generated by solar systems in Sydney in the summers is exported to the grid.

In winters, a much peakier load profile is observed. The evening peak, mostly due to space heating is evident from the load curve above, however due to lower solar insolation levels, the export to the grid is minimised and most of the output of a 3kWp system is used by the customer. Systems greater than that export much of their generated power.

The average annual plot shows that systems up till 2kWp utilise most of the energy generated indoors. 3kWp systems also on an average utilise most of generated power indoors.

With the falling PV prices and rising installed system sizes, it is worthwhile to see if it is even economically viable to install larger systems for Sydney households, as is predicted by some studies.

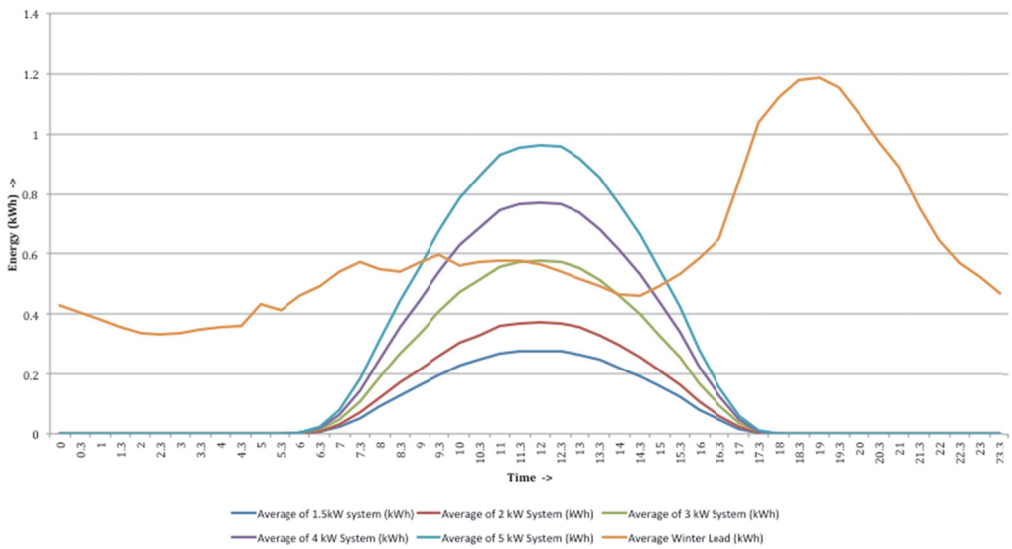


Figure 3: Average PV Generation and Load profile curve for Sydney winter

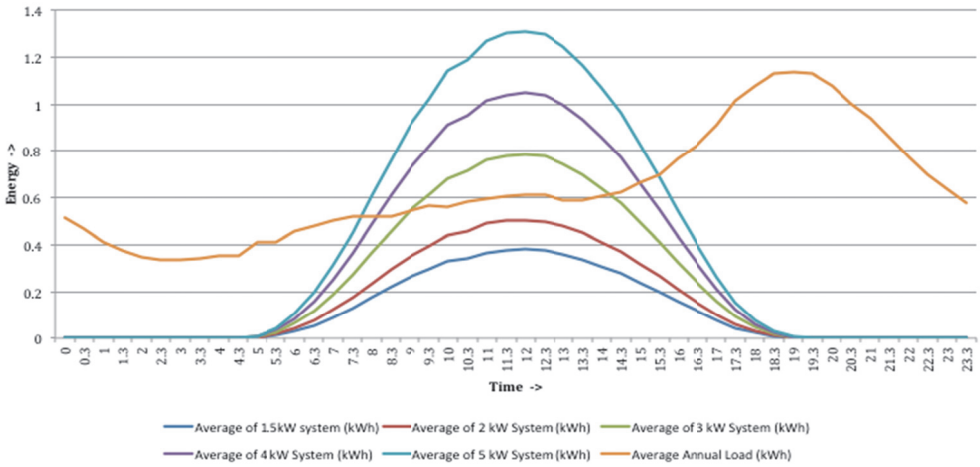


Figure 4: Average annual PV Generation and Load curve for Sydney

## 4 PAYBACK ANALYSIS

The simple payback calculation was performed for the customer based on a year of results obtained from the model. Each possible set of system configuration was analysed for 10 customers. Three sets of FiT scenarios, 0 c/kWh, 5 c/kWh and 8 c/kWh, were modelled for both standard and ToU tariff regimes.
The battery discharge time was fixed from 14 hours to 23 hours. This time was chosen because it included the time of peak tariff and also in case of standard tariff, the time of maximum use.

Figure 5 to 7 prepares a summary of the results by normalising the payback times obtained for different system by the minimum payback time obtained by a systems, for each customer. An average of those values is plotted for different regimes.
Figure 5 plots the results for ToU tariff structure. The y-axis represents the normalised minimum payback time for a system. Figure 6 shows the same analysis for standard tariff structure. The results for different scenarios are added to provide a single graph shown in figure 7.

Though the results would vary for different customers but based on the payback analysis performed under ToU tariff structure, the following broad conclusions can be drawn:

- 1.5kW still gives the lowest payback time irrespective of the FiT values, due to lowest system price.
- It does not make sense to install batteries for 1.5 and 2 kW systems because the customer base load uses most of the generated energy.
- Under no FiT, the payback for 3, 4, 5 kW systems are reduced on installing batteries.
- With a FiT of 8c/kWh, 3 & 4 kW systems have lower payback without batteries but 5kW system fairs better with batteries.

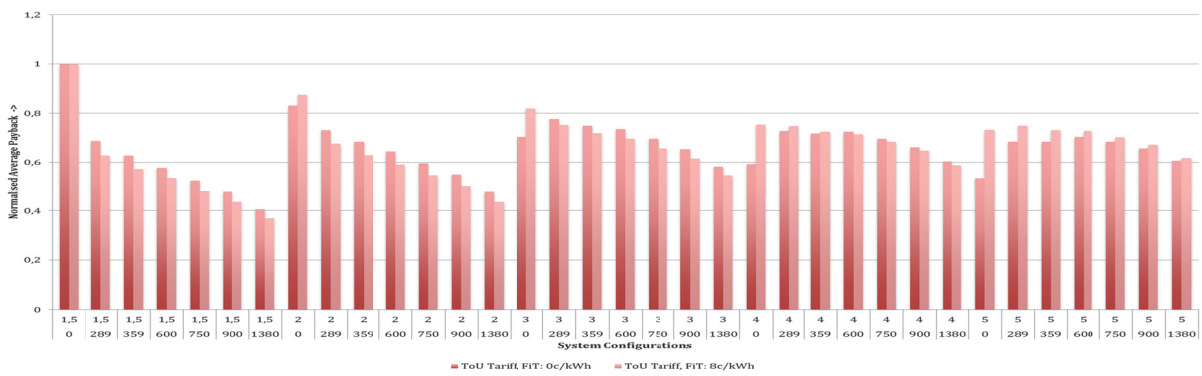


Figure 5: Summary of payback analysis of systems with ToU tariff Structure and FiT:0c/kWh & 8c/kWh

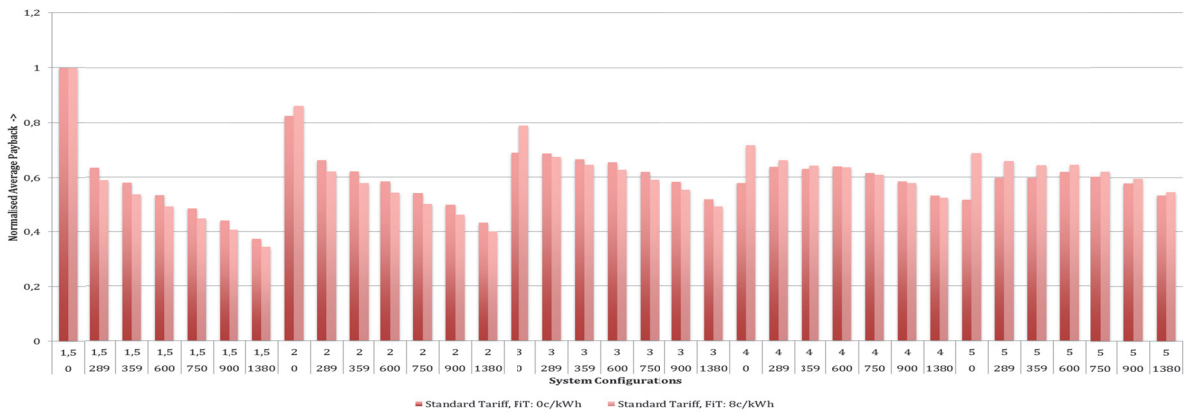


Figure 6: Summary of payback analysis of systems with standard tariff Structure and FiT:0c/kWh & 8c/kWh

For the standard tariff structure, again the results would vary for different customers but based on the analysis performed under standard tariff structure, the following broad conclusions can be drawn:

- 1.5kW still gives the lowest payback time irrespective of the FiT values, due to lowest system price.
- It does not make sense to install batteries for 1.5 and 2 kW systems because the customer base load uses most of the generated energy.
- Under no FiT, the payback for 4 & 5 kW systems are reduced on installing batteries. 3kW systems don't gain much from batteries.
- With a FiT of 8c/kWh, installation of batteries raises the payback period for all system sizes.

In summary, the payback times for smaller systems up to 3kWp are much lower without a battery system in all the cases. The reason being that the smaller systems are unable to charge the batteries up to the desired levels, and hence providing limited economic benefits. The larger 4kWp and 5kWp systems fair better with the battery system installed as most of the power is otherwise exported to the grid for a small FiT.

Also, it should be noted that payback is minimised by optimising the system size, value of time shift and battery costs. Bigger battery system would provide a greater time shift only if sufficiently charged but at the same time might be too expensive due to higher capital costs and vice versa.

## 5 NETWORK ANALYSIS

The impact of the PV and battery systems on the network peak load has been analysed using load data for selection of customers. Three different scenarios have been presented:

### 5.1 Base Case Scenario

The base case involved an existing user connected to the electricity grid, without an installed PV system or batteries.

The individual load data as well as the network load data has been presented. It can be easily observed that the network load peaks during the evening time, when the demand is high. Significant amount of load difference can be seen from Figure 8 and network up gradation may be required in the future to match those rising peaks.

### 5.2 PV Only Scenario

Selection of the households were assumed to have installed PV systems of varying capacities. Its effect on the user yearly electricity consumption and network load was noted (Figure 8). It is visible that 'only PV' has:

- No effect in reducing the network peak load. Network up gradation would still be required to match the future peak hour demand.
- No significant reduction in evening peak grid electricity consumption was observed for the chosen 'typical working households', compared to the base case.

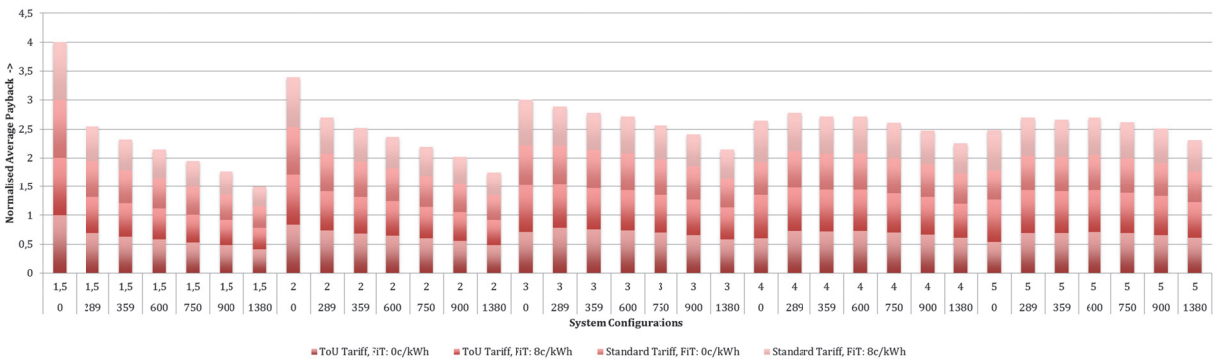


Figure 7: Summary of payback analysis of systems with ToU and standard tariff Structure and FiT:0c/kWh & 8c/kWh

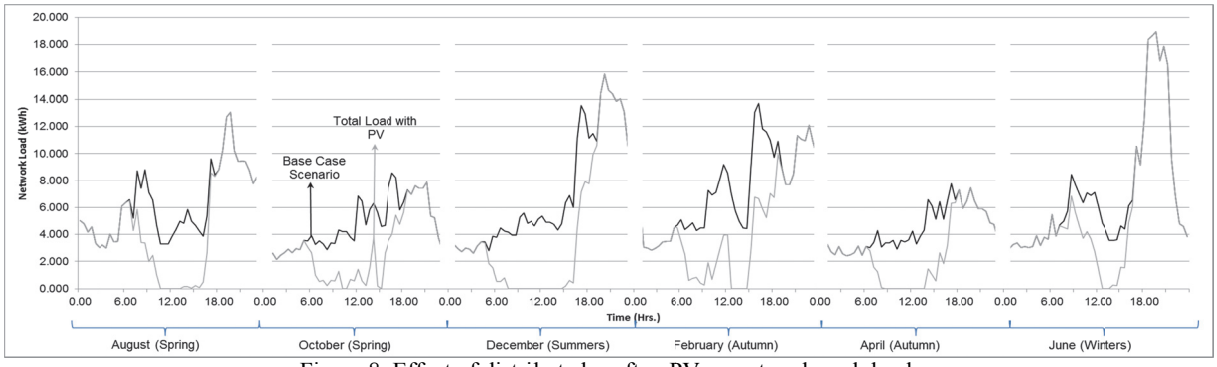

Figure 8: Effect of distributed rooftop PV on network peak load.

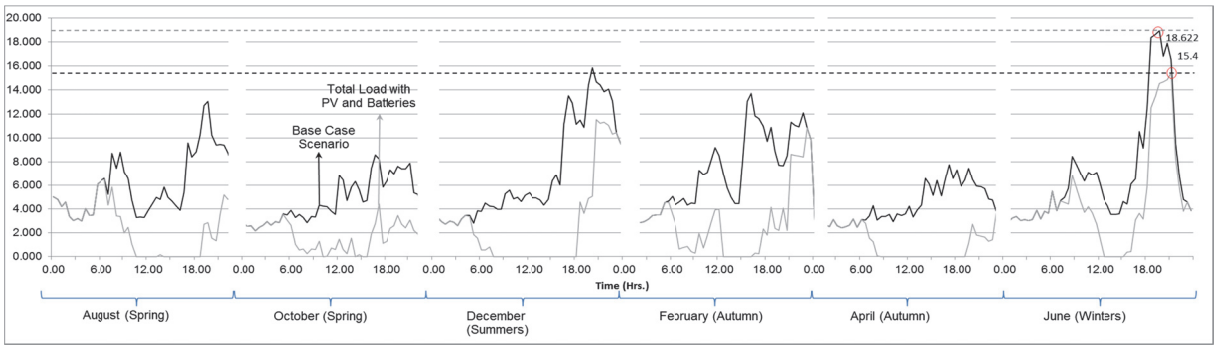

Figure 9: Effect of distributed rooftop PV and battery installation on the network peak load

5.3 PV with Storage Scenario

The selected households were installed with a rooftop PV system and a 24 V battery system of varying capacities. Its effect on peak network load was noted (Figure 9). With installation of batteries in the individual households:

- A reduction of approx. 17% in peak demand was observed for the given load data.
- Increased self consumption and reduced evening peak consumption can also be achieved.

## 6 CONCLUSION & FUTURE WORK

Energy storage can provide an effective way of solving some of the issues with the network, specially the deferring the network augmentation due to peak load. It can add significant value to the residential rooftop photovoltaic systems, if deployed strategically. Significant reductions in payback times can be achieved from the PV systems by storing the excess solar energy and utilising it later, at times of peak demand.

It was felt that a full NPV analysis of the system would be required to accurately predict the economic value of the PV & battery system. The model can be easily expanded to accomodate such analysis. Also, a study on the economic value of network upgrade deferral could further add value to the storage systems.

## 7 ACKNOWLEDGEMENTS

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