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The viability of electrical energy storage for low-energy households

Adrian Grantham [a,*], Peter Pudney [a], Lesley A. Ward [a], David Whaley [b], John Boland [a]

[a] *School of Information Technology and Mathematical Sciences, University of South Australia, Mawson Lakes Boulevard, Mawson Lakes, SA 5095, Australia*
[b] *School of Engineering, University of South Australia, Mawson Lakes Boulevard, Mawson Lakes, SA 5095, Australia*

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ABSTRACT

Electrical energy storage can be used to store excess power generated by domestic rooftop PV systems, rather than exporting it to the grid and then buying back energy at a higher price. We have used one-minute PV generation and electrical load data from thirty-eight low-energy homes to simulate the operation of energy storage, and to calculate the impact on the amount and cost of imported electricity.

The payback period for energy storage systems depends on factors including the cost of energy storage, the cost of electricity, the price paid for exported energy, the power generated by the PV system, and how and when energy is used by the household. We calculate the payback period for various configurations.

Decreasing feed-in tariffs and the decreasing cost of energy storage will lead to an uptake of energy storage system over the next few years. While storage can be used to reduce household electricity cost, it does not lead directly to reductions in CO_2 emissions. However, household energy storage will enable greater use of rooftop PV, and ultimately can be used to match household demand to variable supply from local and centralised renewable energy sources.

1. Introduction

Distributed electrical energy storage has the potential to reduce the CO_2 emissions associated with electrical energy use by enabling greater use of renewable energy sources, such as rooftop photovoltaic (PV) systems. But most electricity distribution systems were not designed to allow flow of power from consumers; as a consequence, there can be limits to how much power may be exported from rooftop PV systems, particularly when there are many PV installations in an area. Furthermore, falling feed-in tariffs mean that it will become increasingly cost-effective to store excess PV energy on site rather than export excess energy to the grid and then import it later at a higher cost.

Hoppmann et al. (2014) provide an overview of many of the studies examining the economics of battery storage for distributed PV systems, as well as including their own analysis. Often, these studies have shortcomings: they are based on simulated loads and PV generation rather than real data, they have low temporal resolution, or they do not study a variety of households.

Many studies simulate PV generation using meteorological variables like solar irradiance and temperature as inputs (Bianchi et al., 2014; Johann and Madlener, 2014; Purvins et al., 2013). Household load profiles are also simulated; Bianchi et al. (2014) generate electrical and thermal load curves by combining the electrical load curves of various appliances found in Italian households. In other studies, the load profiles are synthetic (Weniger et al., 2014). Balcombe et al. (2015) use real PV generation from the open-access PVoutput.org database, where PV users upload their PV generation five-minute data, and obtain real electricity hourly load data from the United Kingdom Energy Research Centre (UKERC) Energy Data Centre. However, the PV generation and load profiles do not come from the same households; PV generation is assigned to a load profile using the assumption that households with greater floor area will have greater PV capacity. Using real PV generation data is important because there can be significant differences between theoretical and monitored PV generation (Whaley et al., 2014). Using real load profiles is also likely to be important.

Most studies use an hourly time scale for modelling generation and load. Some use higher resolution time scales of fifteen-minutes (Bruch and Müller, 2014), five-minutes (Leadbetter and Swan, 2012; Balcombe et al., 2015) and one-minute (Weniger et al., 2014). However, in the study by Balcombe et al. (2015) the hourly load is split into five-minute intervals (to match five-minute PV data) and assumed to be constant over the hour. While hourly time scales capture some of the variation in household PV generation and load, there will be significant variations within an hour.

PV generation across many households should be consistent given similar PV system parameters, however in reality this is often not the case (Whaley et al., 2014). Also, no two household load pro-

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* Corresponding author.
E-mail address: adrian.grantham@unisa.edu.au (A. Grantham).

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files are alike. Therefore, a variety of households need to be examined in order to provide robust results. Balcombe et al. (2015) examines 30 households from the UK. However, as stated earlier, the households with PV generation data are different to the households with load profile data.

Most studies comment that the investment in household energy storage is viable if the cost of storage is low enough. However, the studies do not provide households with a simple tool to determine how much storage should be bought.

Our work examines the impact and viability of a household battery storage system using real PV and load data, at one-minute time scales, for a variety of households. The results are presented in a way that allows households with existing PV, and knowledge of their annual energy export, to assess the economic viability of different capacity battery systems.

This paper is organised as follows. Section 2 provides a description of the Lochiel Park data, defines terminology, and gives details of the tariffs considered. Section 3 shows some example household load profiles and discusses which households might benefit from an energy storage system. Section 4 describes the storage simulation process discusses simulation results. Section 5 looks at the economics of home energy storage by calculating the payback period for various configurations. Section 6 presents the simulation data in a way that can be used by householders without detailed data logs to estimate their ideal amount of storage. The paper concludes with a summary and suggestions for future work.

2. Data and preliminaries

Our data was obtained from households at Lochiel Park in Adelaide, South Australia. Lochiel Park is a development of about 100 homes designed to demonstrate housing with low energy and water consumption. In addition to energy-efficient design, each house has at least 1 kW of PV panels for each 100 m^2 of habitable floor area. Each household's use of electricity, gas and water is logged. The electricity logs include PV power and total electrical load at one-minute intervals.

We used one year of PV and load data from each of thirty-eight households. The households were selected because they had mostly complete data for the year 2013. Detailed information about their rooftop PV installation was also available.

The data for each household includes the average PV power generated and the average household load for each minute of the year. The difference between the load and the PV power is the power demanded from the grid. The households have net metering agreements; they pay for electrical energy imported from the grid, and are paid for electrical energy exported to the grid. Most of the households currently receive feed-in prices that are greater than the import cost of electricity, so it is more cost-effective to export energy than it is to store it to use on site; but as feed-in tariffs drop far below the cost of imported electricity, storage may become viable.

None of the houses have electrical energy storage systems. Our aim was to analyse the potential impact of electrical energy storage on energy use and electricity costs, and to calculate the viability of electrical energy storage systems.

We use the following terminology:

- *load* is the total power being drawn by electrical appliances in a household
- *generation* is the total power being generated, usually by a rooftop photovoltaic system
- *demand* is the power that must be imported from the electricity distribution network.

Load, generation and demand are related by:

$$\text{demand} = \text{load} - \text{generation}$$

If generation exceeds load then demand is negative, and power is exported to the grid.

With electrical energy storage, the relationship becomes

$$\text{demand} = \text{load} + \text{storage} - \text{generation}$$

where storage is positive when power is stored and negative when power is retrieved.

We considered two different energy tariffs; a flat tariff and a time-of-use tariff. The flat tariff represents a typical flat tariff on offer in South Australia. The time-of-use tariff is a time-of-use tariff on offer in Queensland, Australia. The tariffs are:

- *Flat tariff*: The cost of imported energy is 30 c/kWh, and the price paid for exported energy is 6.8 c/kWh.
- *Time-of-use tariff*: The cost of energy is 47.12 c/kWh during peak periods, between 15:00 and 21:30 on weekdays during the summer months. During off-peak periods the cost of energy is 17.334 c/kWh. No price is paid for exported energy.

We can ignore any daily supply charge, since we are interested in the difference in costs with and without storage.

We analyse electrical energy system with four different capacities. The details are provided in Table 1.

We assume that the energy storage system has a constant energy efficiency $\eta_s = 0.90$; only 90% of the electrical energy applied to the storage system can be retrieved. This efficiency factor is typical for a lithium ion battery storage system, and takes into account losses in the charger and inverter electronics, and in the electrochemical cells (Rydh and Sandén, 2005; Battke et al., 2013; Sullivan and Gaines, 2012).

3. Household demand and power load

We analysed the load, generation and demand of each of thirty-eight households during 2013. Figs. 1–6 show the demand profiles of six selected households. The horizontal axis on each graph is the local time of the week, from Sunday to Saturday. There is one trace for each of the 52 weeks of the year on each graph. The year is divided into two seasons: summer (daylight savings period) and winter (standard time). The orange lines show one-minute demand during summer, and the light blue lines show one-minute demand during winter. The bold red line is the median demand during summer, and the bold blue line is the median demand during winter. Demand is negative when the household is exporting energy.

Figs. 4 and 6, for households 13 and 18 respectively, show very little export during the day, so these households may not be good candidates for energy storage. Compare these to households 3 and 8, Figs. 2 and 3 respectively, who export more during the day.

4. Storage simulation

The strategy for operating the electrical energy storage system for the flat energy tariff is summarised in Table 2.

Table 1
Battery storage systems.

Usable capacity (kWh)	Charge/discharge power (kW)
2	2.3
4	4.6
6	4.6
8	4.6