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Short Communication

Control strategies of domestic electrical storage for reducing electricity peak demand and life cycle cost

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ABSTRACT

Electricity grid capacity is often oversized to ensure it accommodates maximum anticipated peak demand. In South Australia, 25% of the grid capacity is required for less than 1% of the time. To reflect the cost of peak demand in electricity tariffs, demand tariffs consider not only electrical energy consumption (kWh), but also electrical power demand (kW) during a peak period which is from 16:00–21:00 in South Australia. Demand tariffs increase electricity costs for users needing intermittent electrical energy supply with large electrical peak power demand. To reduce the peak demand and the subsequent electricity cost, batteries are being included in the energy system. In this paper, four control strategies are developed for charging and discharging a battery, and to export and import electricity from the grid. The strategies are simulated with and without a photovoltaic (PV) system using real-time monitored electricity consumption and gross PV generated electricity of a monitored energy-efficient house. The results show that using PV with electrical storage and proper control strategies can reduce both the electricity peak demand and life cycle cost. These results are timely given the recent emergence of small-scale storage technologies and the prediction that these technologies may become commonplace in the near future.

Introduction

The residential sector accounts for a significant proportion (25%, 1041 PJ) of Australia's total energy consumption [1], with most of this energy being produced from polluting fossil fuels. The use of renewable energy technologies, such as solar energy, reduces the reliance on polluting fuels. The use of solar energy technologies is being further encouraged in the residential sector by the dropping cost of photovoltaic (PV) modules and the escalating cost of utility purchased electricity.

South Australian photovoltaic feed-in tariffs

In South Australia, rooftop PV systems were initially encouraged by generous feed-in tariffs that paid customers for energy exported at twice the rate of that imported from the grid. These feed-in tariffs have been reduced to considerably less than the price of imported electricity. Currently, householders supplying electricity to the grid may be eligible under specific conditions for a minimum retailer payment, which can be as low as 5.3 cents per kWh exported to the grid [2]. Under the current feed-in scheme, exporting surplus electricity to the

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grid provides minor economic benefits, as the average price of 1 kWh imported from the grid is more than 30 cents [3,4]. Storing excess PV generated electricity on site for later use, rather that exporting electricity to the grid, is becoming a more attractive alternative, especially with the move towards demand tariffs which will become mandatory in 2017, and the continual decrease of battery costs. Lithium–ion (Li–ion) batteries are commercially available for AUD$1100/kWh [5].

Shift to time-based demand tariffs

Conventional electricity tariffs are based on the consumption of electricity (kWh) regardless of the time of consumption. However, electricity tariffs are changing to better reflect the costs of peak demand. The demand frequency distribution for South Australia reveals that the peak demand is approximately twice the mean demand as shown in Fig. 1 [6]; 25% of the electricity capacity is used less than 1% of the time. The oversized capacity needed to supply peak demand for short periods adds to electricity distribution costs, which are passed on to the end-users. New electricity demand tariffs will be based not only on the total electricity consumption (kWh) but also on the monthly peak demand (kW) of electricity measured every 30 min from 16:00–21:00, with a baseline peak demand rate set at 1.5 kW.

Previously examined control strategies

Researchers have investigated the impact of electricity storage and control strategies on reducing the electricity cost under different non-demand tariffs in Refs. [7,8], whilst three control strategies for reducing peak demand from the grid were simulated in Ref. [9]. The strategies included charging the battery from the grid and PV, and discharging the battery to maintain the demand to a desired magnitude. The results showed that electricity storage could be economic for different non-demand tariffs. A separate study considered optimizing both the storage capacity and the control strategy and evaluating the profitability of installing a storage system [10]. The strategy consisted of charging the battery from the grid only when the cost of electricity is low and discharging the battery only when the cost of electricity is high, which made this strategy useful for time-of-use and real-time pricing tariffs. The results showed that a reduction of the battery cost by more than 50% was required to make the installation of an electricity storage system profitable [10].

The review reveals that research on using electrical storage and control strategies as a means to reduce the peak demand and life cycle cost (LCC) of electricity have been limited. This paper evaluates the impact of the size of both PV and storage systems and investigates four control strategies for managing the stored energy to reduce the monthly peak demand and reduce the 20-year LCC of electricity under a monthly demand tariff. Although these strategies exhibit some similarities with those presented in Ref. [9], the strategies presented in this paper use a novel charging approach which maximizes battery charging from PV generated electricity.

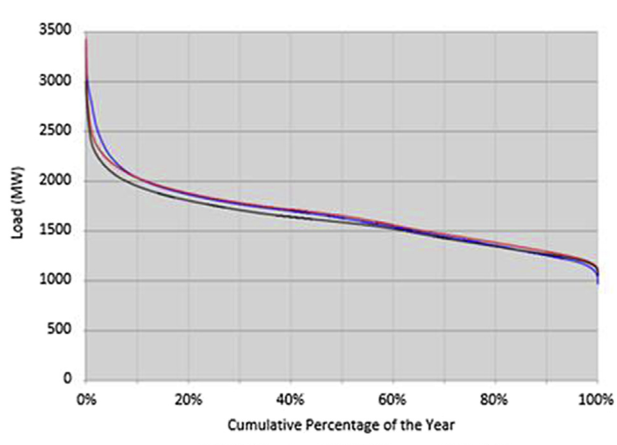

Fig. 1 – Electrical load duration in South Australia [6].

Methodology

The impact of domestic electrical energy storage on the monthly peak demand and the LCC of electricity is examined for an energy-efficient house which has an annual electricity consumption (6265 kWh) similar to the average annual electricity consumption of Australian residential sector (5915 kWh) [11]. The house is located in Australia's most comprehensively monitored and sustainable housing estate, Lochiel Park. This Green Village is an exemplary energy-efficient housing estate that contains approximately 70 energy-efficient houses that each utilize a grid-connected PV system, gas-boosted solar water heater, an in-home display and energy monitoring system with an array of intelligent meters and sensors [12,13].

The analysis presented in this study uses real-time, monitored gross PV generation, total household electricity consumption, and imported and exported electricity data for a period of 12 months together with a simulated battery system using one of four battery charging/discharging control strategies. The data from the selected household has high-resolution of 1-min which provides detailed information about the electricity consumption and production. The data have been processed to generate 5-min resolution to reduce the computation time, whilst maintaining sufficient details of electricity imported and exported, i.e. within 30-min intervals [14].

Energy storage properties

The impact of introducing the energy storage system on monthly peak demand and LCC depends on battery properties which are summarized in Table 1 [15]. In addition, the impact is affected by the system cost, the demand tariff and the

Table 1 – Assumed battery properties.

Type	Li–ion
Charging efficiency	96%
Discharging efficiency	96%
Minimum state of charge (SOC)	20%
Charging time	180 min
Capacity	Varies
Battery life	10 years

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