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Availability and network impacts of battery electric vehicles used for peak shaving.

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Abstract

Battery electric vehicles (BEVs) have long been recognised as potential contributors to electrical power system operation and enhanced asset management. However, relatively little research has been reported on the likely availability of BEVs for peak shaving in local networks, nor on the impact of overnight recharging on local feeder demand profiles. In this study, thirty households in Halswell, Christchurch were asked to keep a travel diary during two 1-week periods in the winter and spring of 2013 respectively, to determine the potential availability of BEVs for peak shaving at the local 11 kV feeder. Full responses were received from 19 and 16 households, representing 2.6% and 2.2% of households, respectively. The study found that availability ranged from 26% to 94% of vehicles, and that the energy available prior to shaving averaged 18.4 kWh per vehicle, or 77% of battery capacity. Demand greater than a chosen limit of 1400 kW (30-min) occurring during morning and evening peaks could be shaved by drawing down 0.01 to 4.1 kWh per vehicle, that is under 0.1% to 17% of battery capacity. However, the additional load required for overnight recharging following daily travel was found to dominate the new demand profile, with night-time peaks in excess of both the adopted limit, and previous maxima. Similar results were found for recharging only. It was concluded using BEVs for morning and evening peak shaving in this situation would add no value, and that spreading the recharging load over 24 hours would be a preferable focus for future investigation in this particular area. Prospects for other V2G services are discussed. Further research to replicate the study in differing geographic and socio-economic areas is suggested.

1. Introduction

The idea of electric vehicle to grid (V2G) interaction was first proposed by Kempton and Letendre (1997). It was observed that light vehicles in the USA were idle for over 95% of the time and suggested that, should they be electric vehicles, grid interaction would be both possible and beneficial. Peak power provision, regulation and supply of spinning reserves have been proposed and evaluated as grid services, along with enhanced integration of variable renewables generation e.g. (Kempton and Letendre, 1997; Kempton and Tomic, 2005a; Kempton and Tomic, 2005b; Tomic and Kempton, 2007; Lund and Kempton, 2008; Sioshansi and Denholm, 2010). Complete replacement of regulating power stations by V2G was suggested by Lund and Kempton (2008). The use of V2G for peak shaving and valley filling has been investigated by Wang and Wang (2013). Forecast benefits for generators and transmission/network operators have included deferment of new plant and/or system upgrades, and maximising usage of existing assets. For the vehicle owner the major benefit identified was the opportunity to sell energy services back to the grid. Commercial vehicle fleets such as delivery vehicles, or fork lift fleets, have been seen as attractive candidates for initial V2G implementation due to their predictable availability patterns (Kempton and Tomic, 2005b; Tomic and Kempton, 2007). However, the much greater potential in non-fleet vehicles has been well recognised e.g. Kempton and Tomic (2005b).

Concerns raised have included decreased battery life, transmission bottlenecks, power quality issues, increased transformer wear and higher peak loads when simple charging strategies are employed. Richardson (2013) provides a comprehensive review of such issues. A financial advantage to utilities has been predicted, despite the costs of connection and impacts on vehicle battery life (Kempton and Letendre, 1997; Kempton and Tomic, 2005a). Regarding battery life, frequent shallow discharge cycles have been reported to typically give much greater life than fewer deep cycles (Kempton and Tomic, 2005a), indicating that regulation would be a preferable use to peak power or spinning reserves provision. Solutions for compensating BEV owners for decreased battery life proposed by Kempton and Letendre (1997) were for a utility to: a) offer a subsidised electricity rate; b) offer a purchase subsidy on the vehicle; or c) take ownership of battery. Impacts of depth of discharge and ambient temperature on battery life were reported by Zhou et al. (2011) who concluded that Li-ion batteries with thermal management systems could result in financially favourable use of BEVs for peak shaving in the UK, but not in China, at least under existing tariff conditions. Financial benefits for plug-in hybrid vehicle owners were predicted by Sioshansi and Denholm (2010), for electric vehicle owners using V2G for regulation by Han and Han (2013), and for BEV owners using smart charging regimes by Schuller et al. (in press).

Published studies on vehicle availability and impacts on electricity systems typically use generalised travel scenarios and examine the impacts at national or regional, rather than local, levels. For example a simulation study by Monigatti et al. (2012) examined the potential for BEVs to supply reserve generation in a scenario involving greatly increased penetration of wind generation in New Zealand, with energy flows examined at a national level. For a review of the ability of electric vehicles to facilitate increased penetration of variable renewables generation the reader is referred to Richardson (2013).

The objectives of the present research were to: a) determine the potential availability of BEVs in a suburban area of Christchurch, New Zealand, at times of peak demand on the local network; b) to estimate the potential for shaving peak loads at the local feeder; and c) to estimate the impact over-night 'at home' recharging on demand at the feeder.

2. Methods

2.1 Survey

Households were sampled from the area served by a 6750 kW (approx.) feeder in the suburb of Halswell, Christchurch in May, 2013 (Fig. 1). Approximately 60 addresses were randomly selected, and then sequentially requested to take part in the study until 30 households had agreed to participate and signed a consent form.

Households were asked to keep a light vehicle travel diary for two 1-week periods in winter (22-28 July, 2013) and spring (9-15 September, 2013). Departure and arrival times from and to home, odometer readings, and the approximate time (25, 50, 75, 100%) spent in three speed zones (0-50; 50-80; 80-100 km/h) were requested. Useable responses were received from 19 and 16 households respectively, giving 63% and 53% response rates. As several households reported data for a second vehicle, information for a total of 23 vehicles for the winter period, and 18 vehicles for the spring period, was collected.

The survey instrument was pilot tested prior to implementation and approved by the University of Canterbury Ethics Committee.

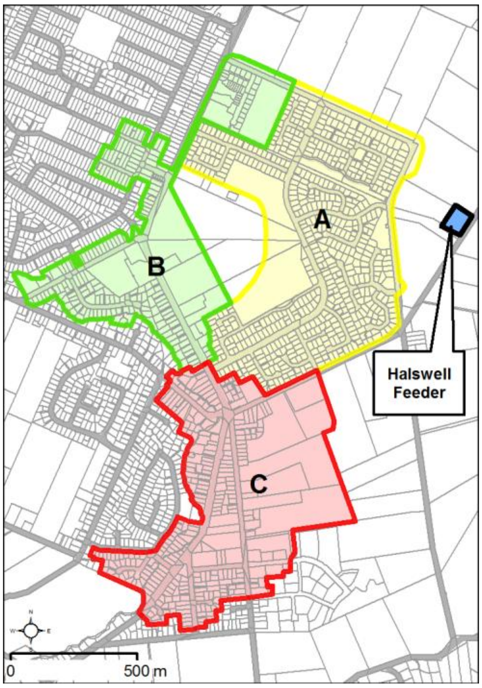


Figure. 1: Halswell study area: i) households surveyed were located in areas A, B and C; ii) the feeder served only area A, between Jul-Sep, 2013.

2.2 Demand data

Demand data at the feeder for the two 1-week periods was obtained from the local distribution company as 30-min 11 kV amps, and converted to kW. Peaks were defined as those parts of the demand curve above a specified limit, the value of which given in section 3.1 below.

2.3 Analysis

In July, 2013 the feeder was switched to supply only area A in Fig. 1, but this was not known to the researchers at the time. For the purposes of this study therefore it was assumed that vehicle travel patterns reported by households in areas B and C were representative of those within area A. This seems reasonable given the relatively homogenous nature of the suburb.

Each vehicle was assumed to be a Nissan Leaf (Fig. 2) with a 24 kWh battery, and a home charging point available. If vehicles were parked on the property for the full duration a peak period they were considered to be ‘at home’. BEVs unable to be fully charged by 0600 each day, and thus be available for the morning peak, were excluded from peak shaving. Availability for the evening peak was then determined for vehicles ‘at home’ by calculating the remaining ‘fuel’ after each vehicle’s daily travel, plus the overnight recharging time needed. Vehicles unable to be recharged by 0600 the following day were excluded. Where no data was entered, the vehicle was assumed to be unavailable for peak shaving. Peak shaving availability was then scaled up to all 723 households in the area supplied by the feeder and the energy per vehicle needed to shave the identified peaks at the feeder determined. Vehicle energy use values of 6.12, 5.46 and 4.84 km/kWh for the 0-50, 50-80 and 80-100 km/h speed zones were derived from USEPA test data for the Nissan Leaf (USDOE, 2014). Discharge losses of 5% were assumed.

Figure. 2: The Nissan Leaf BEV including a view of the battery pack (orange)

Vehicle recharging was confined to the cheap night-rate period applying in the study area of 2100 h to 0700 h. This period was shortened where: a) vehicles arrived later home than 2100 h and departed prior to 0700 h the following day, and/or; b) an evening peak extended beyond 2100, or a morning peak commenced prior to 0700 the following day. Where a vehicle had used more than a full charge prior to arriving home, it was assumed that the vehicle had recharged en route, and required only a 12 kWh top-up overnight. A simple recharging strategy whereby all vehicles were recharged at the lowest possible rate was adopted. Recharge losses of 5% were assumed.

3. Results and Discussion

3.*1* *Demand patterns*

Demand at the feeder (30-min kW) demonstrated the expected daily patterns, with distinct morning and evening peaks (Fig. 3). Maximum half-hourly morning demand typically occurred between 0600-0800 on weekdays and also the spring weekend. In winter, the Saturday-Sunday morning maximum was from 1000-1030. Evening half-hourly maxima usually occurred from 1800-1930. Based on these results a limit of 1400 kW, which allowed morning and evening peaks to be shaved without affecting lesser peaks occurring at other times, was chosen. Peak duration ranged from 0.5 to 5.0 hours. In the spring week, peaks in excess of 1400 kW occurred on Monday and Tuesday, and Sunday evenings, only.

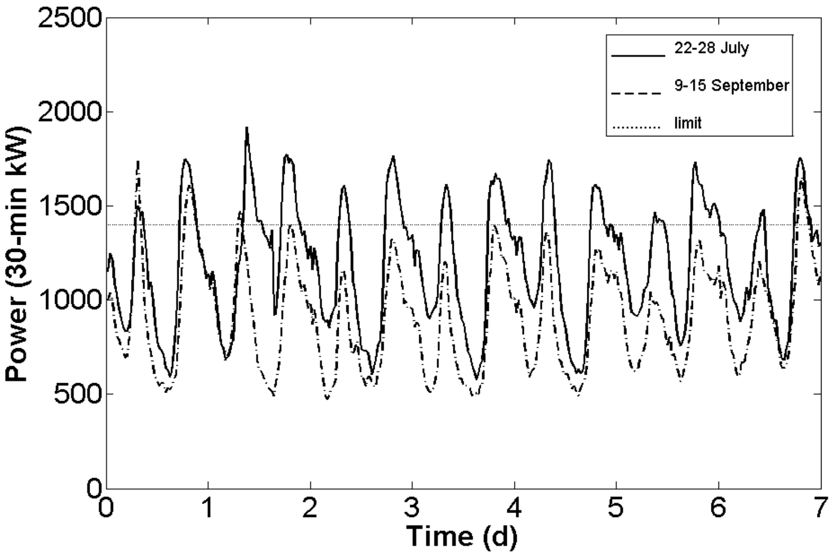
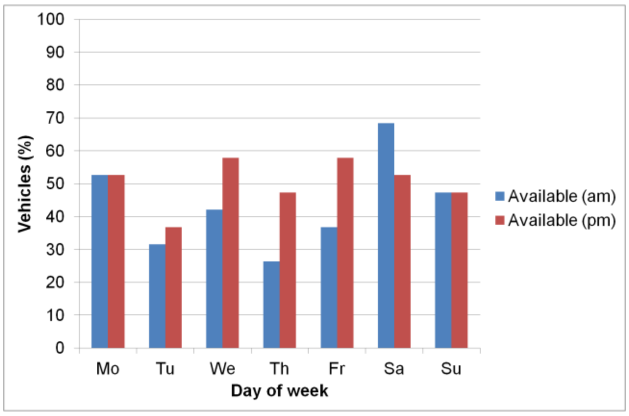


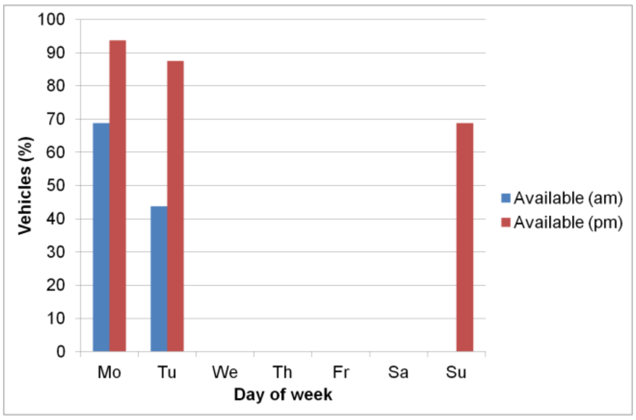
Figure 3: Half-hourly demand from Mo-Su, 22-28 July and 9-15 September, 2013.

3.2 Vehicle availability

The study found that availability for morning and evening peak shaving ranged from 25% to 68% (190 to 495 vehicles) in the winter week, and from 44% to 94% (316 to 678 vehicles) for the applicable days in spring. The pattern of vehicle availability for peak shaving is shown in Fig. 4a-b. Demand did not exceed 1400 kW from Wednesday-Sunday am in spring.



a)



b)

Fig. 4: Vehicle availability during peak periods; a) 22-28 July, 2013; b) 9-15 September, 2013.

3.3 Peak shaving

Battery energy remaining after daily travel averaged 17.4 kWh (range -21.9 to 24.0 kWh) in July and 18.0 kWh (range -30.0 to 24.0 kWh) in September. By drawing down 0.15 to 4.14 kWh per vehicle in July and 0.01 to 0.56 kWh per vehicle in September, all peaks could be ‘shaved’ so that demand at the feeder would not exceed 1400 kWh. The average depth of discharge, including the energy used by prior travel, was 29% (maximum 95%) and 30% (maximum 82%) for July and September respectively. The results of peak shaving in this way can be seen in Fig. 5a-b.

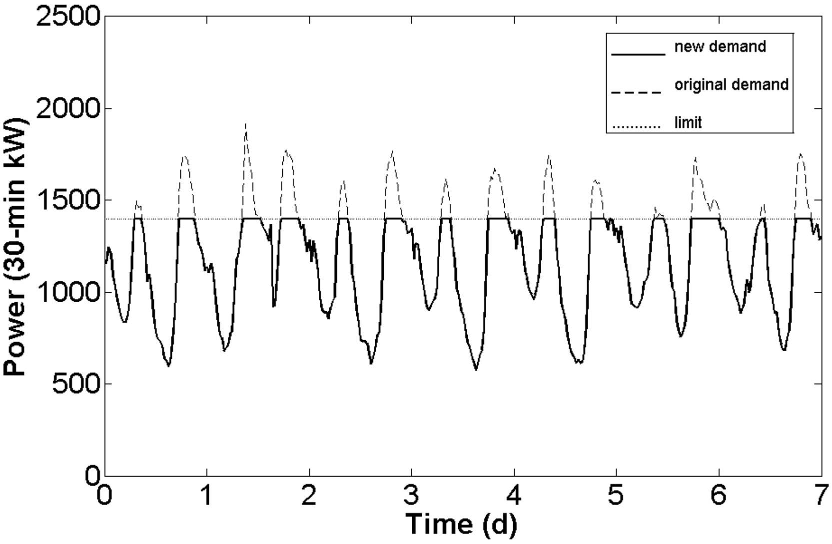


Fig. 5a: Half-hourly demand pattern with peak shaving; 22-28 July, 2013.

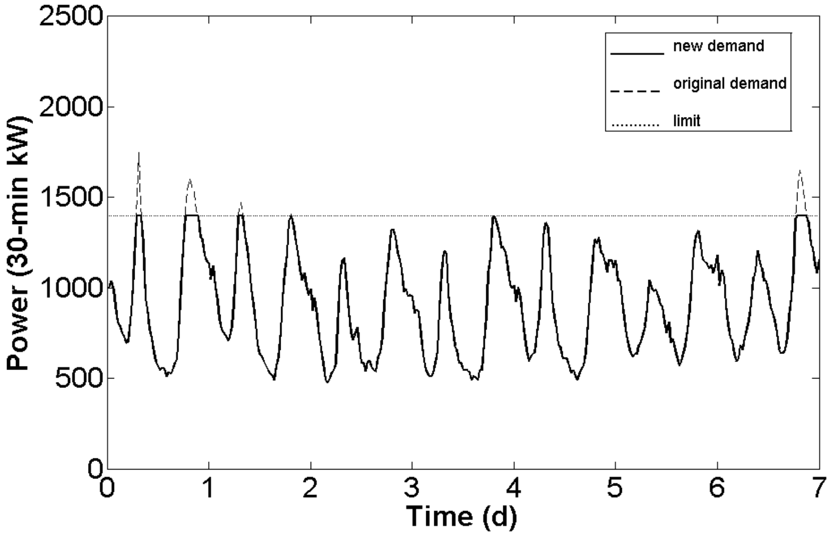


Fig. 5a: Half-hourly demand pattern with peak shaving; 9-15 September, 2013.

3.4 Peak shaving with recharging

The majority of vehicles were found to be ‘at home’ during the low-tariff period of 2100 h to 0700 h, and thus available for recharging during this time. The results of the simple recharging strategy, in which the load was spread evenly over the time available, are shown in Fig. 6a-b. A picture of significantly increased night-time loads, in excess of previous peaks, is clear. Peaks in the new profiles could be lowered somewhat by optimizing the recharging strategy to fill the valleys in the latter part of the night. Models for peak shaving/valley filling, optimal recharging and minimizing grid congestion, are available e.g. (Wang and Wang, 2013; Hu et al., 2014; Schuller et al., in press). However in the present case, peak loads would remain significantly greater than those in the control scenario. Individual vehicle recharging rates did not exceed 3.2 kW.

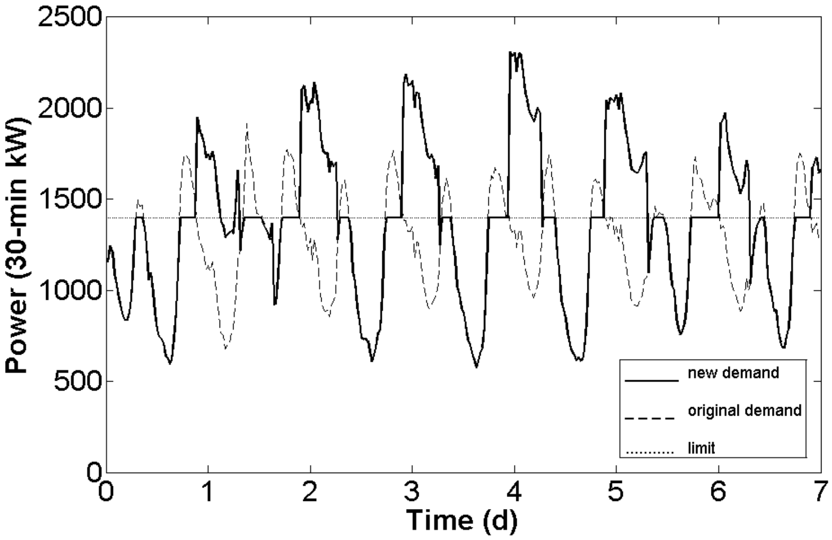


Fig. 6a: Half-hourly demand pattern with peak shaving and recharging; 22-28 July, 2013.

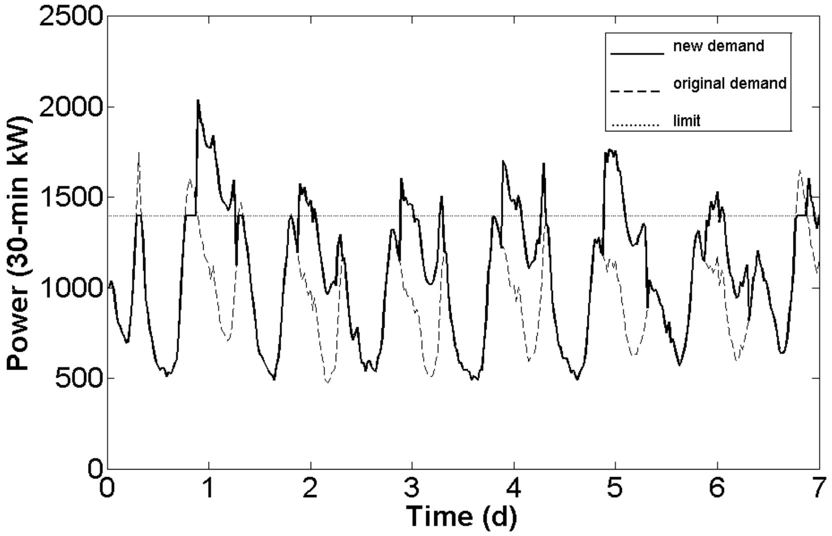


Fig. 6b: Half-hourly demand pattern with peak shaving and recharging; 9-15 September, 2013.

3.5 Recharging only

The demand profiles for recharging in the absence of peak shaving, are shown in Fig.7a-b. Whilst the reduced load is apparent, the new demand profile remains characterised by night-time peaks in excess of previous day-time maxima. This reflects the relatively high energy requirement for recharging in comparison to that needed for peak shaving in this case. As above, some degree of smoothing would be possible using a smart charge controller.

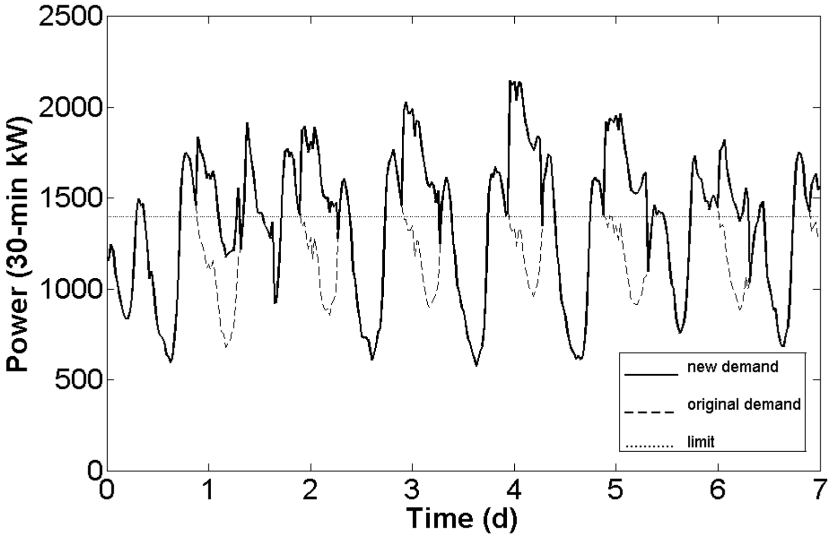


Fig. 7a: Half-hourly demand pattern with recharging only; 22-28 July, 2013.

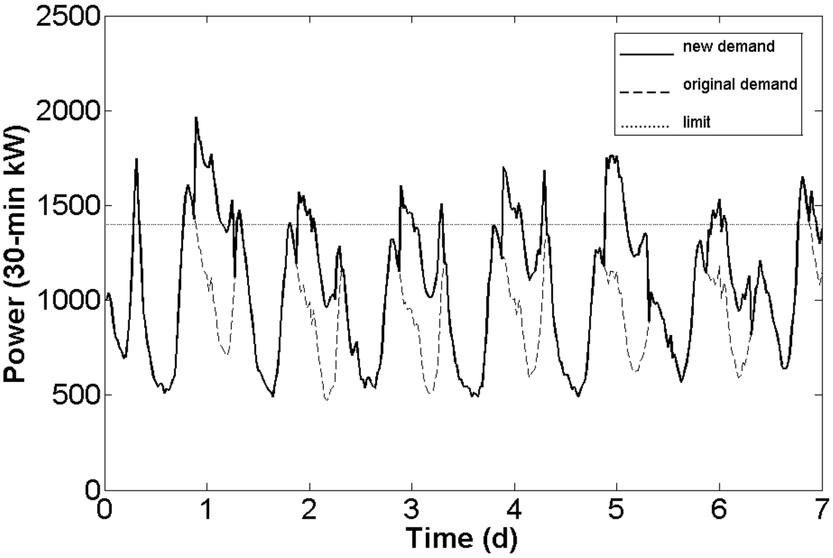


Fig. 7b: Half-hourly demand pattern with recharging only; 9-15 September, 2013.

3.6 General Discussion

The magnitude of the impact of overnight recharging on the demand profile has emerged as the dominant outcome of this investigation. Whilst sufficient vehicles were found to be ‘at home’, and with enough remaining energy for peak shaving, any resulting flattening of the profile was found to be out-weighed by recharging demand during the low-tariff night-time period. This suggests that implementation of strategies designed to spread the recharging load over the day and the night, targeting the valleys wherever they occur, should be a priority where maximum feeder capacity is approached. Such techniques will need to accommodate existing peak shaving methods such as ripple control of hot water heating. In addition to using smart charge controllers to optimise recharging, the impact of fast-charge installations, which are already appearing in New Zealand, should be considered when investigating the minimisation of new peak loads and the flattening of demand profiles.

Using BEVs for peak shaving in this context thus appears of limited value, at least until new demand profiles, resulting from full electrification of the light vehicle fleet as assumed in the present study, are known with greater certainty. The supply of spinning reserves and regulation services, as proposed in the literature, is similarly likely to be of limited interest, considering the availability of existing renewable generation, i.e. hydro, to supply such services in New Zealand, as opposed to the use of high- or moderate-cost plants in other countries e.g. Kempton and Tomic (2005b). However, in the event of a large increase in wind generation, as planned in Denmark for example, BEVs may provide a useful option for utilising surplus electricity production and avoiding, or minimising, curtailment. A complication may arise if domestic and parking lot installations of PV systems become widespread in New Zealand. Owners of BEVs may then choose to recharge off-grid, either fully or partially, in which case the demand profile at a feeder, such as that in the present study, will be less impacted by overnight on-grid recharging. In that case, using BEVs to supply certain grid services, including the use of battery storage to manage over-voltage (Tant et al., 2013), may re-emerge as an interesting prospect. Additionally, BEV batteries could provide useful backup electricity during emergency outages at the feeder e.g. Kempton and Tomic (2005b), which capability may be particularly attractive in Christchurch.

Impacts of grid service provision on battery life require further attention. In addition to continued technical review, financial analyses such as those published by Zhou et al. (2011) require re-evaluation under New Zealand conditions. Studies of the likely acceptability of any proposed compensatory policies to BEV owners should also be considered.

3.7 Limitations of this study

This research was confined to a single suburban area of Christchurch, with a particular demographic, and needs to be replicated in different locations, both within the city and elsewhere, before more general conclusions about local network impacts of BEVs in New Zealand can be made. A number of households with more the one vehicle reported travel for only one of those vehicles, resulting in an underestimation of peak-shaving, and recharging, impacts. In cases where no travel data were recorded for a particular day, assumptions concerning vehicle availability for both peak shaving and recharging were made. Finally, an assumption of full electrification of the light vehicle fleet was made, whereas a future mix of BEVs and internal combustion vehicles, the latter running on biofuels, is a possibility.

4. Conclusions

Sufficient vehicles were found to be 'at home', and available, to enable peak shaving in the study area to a level of 1400 kW, provided all vehicles were BEVs. Peaks were shaved by drawing down 0.01 to 4.1 kWh per vehicle.

Recharging loads, when utilizing a simple over-night recharging strategy, resulted in new peaks which exceeded previous maxima. Attention to implementing smart recharging systems for more evenly distributing these loads is suggested.

Prospects for V2G grid services, including peak shaving, provision of spinning reserves and regulation, appear limited within the context of this study.

Further research is suggested to investigate whether the findings of this study are applicable in differing geographic and socio-economic locations.

Acknowledgements

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