Impacts of new technologies on load profiles

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Abstract

Desires to reduce reliance on fossil fuels and reduce greenhouse gas emissions, as well a period of technological development and falling technology prices, has led to increased interest in the use of new technologies in the energy sector. This paper, resulting from the GREEN Grid research program, presents initial analysis on the effects of three emerging technologies on the load profiles experienced by electricity distribution businesses. These three technologies are distributed photovoltaic generation, electric vehicles, and home energy storage systems.

Widespread adoption of these technologies has the potential to cause a number of effects in the power system due to changing load profiles and the subsequently changing power flows. This paper presents modelling work firstly of the impacts of photovoltaic generation on load profiles. Regional variations in solar insolation and population density are taken into account. Secondly, the load of electric vehicle charging is modelled under different electric vehicle uptake and charging methodology scenarios. Thirdly the ability of EDB controlled energy storage systems to reduce peak load both with, and without, PV generation is modelled.

The conventional notion that PV generation has no ability to reduce peak loads is tested, with results showing that while largely true there are some scenarios which challenge that notion. In the case of high rates of electric vehicle uptake and uncontrolled charging it is shown that a significant increase in the evening peak is to be expected. With more considered rates of electric vehicle uptake and charging delayed until late evening, either controlled or incentivized with night rate tariffs, it is shown that load impacts are minimal. Initial modelling of home battery energy storage systems show great promise in ability to reduce daily peaks given deployment in substantial numbers.

Introduction

Desires to reduce reliance on fossil fuels and reduce greenhouse gas (GHG) emissions, as well a period of technological development and falling technology prices, has led to increased interest in the use of new technologies in the energy sector. This paper presents modelling of solar photovoltaic (PV) generation, electric vehicles (EVs), and home battery energy storage systems on the loads experienced in EDB networks.

In an uncontrolled system, without storage it is expected that PV generation will reduce day time load and make negligible, if not zero, reduction to the evening peak. Electric vehicles may however increase the evening peak as people arrive home from work and plug in their vehicles for charging. In order to defer and reduce both network investment it is desirable to flatten the load across the day. Home battery energy storage presents one opportunity for flattening load profiles. Intelligent charging methodologies also present an opportunity for load flattening; many people arrive home in the evening and do not require their vehicles again until morning meaning there is no reason why charging must commence immediately rather than during the low load period of late night/early morning.

This paper presents initial modelling of the changes that a range of these technologies will have on network load profiles. This impacts of the technologies have been modelled at an EDB level, though in future it is planned to expand the analysis down to the GXP and feeder level. There are a number of other items planned as future research:

- Use of these models of changing loads to model changes to power flows and understand the impact on network assets
- Understand the economic implications of these new technologies
- Explore methodologies for the control of home energy storage systems

Data Sources

Loads for EDBs have been taken from the Electricity Authority's EMI half-hourly dataset. In all modelling work referred to in this paper the load of an EDB is considered the sum of GXP import quantities and embedded generation.

Photovoltaic modelling uses solar radiation data from NIWA at a 10 minute resolution which has been processed by Scott Lemon to give a Watts generated per Watt installed value. This modelling assumes the PV panels are installed facing North with a 30° tilt and inverter sized to the panels.

Electric vehicle uptake and transport statistics are taken from Ministry of Transport data, as well as published data on a variety of models of electric vehicles.

Photovoltaic Generation

As at 31 March 2016 New Zealand has an installed PV capacity of 36.774 MW [1], which corresponds to 7.9 Watts per person. This is compared to a selection of other countries in Table 1 with the figure for New Zealand at a comparable time included. It is clear that New Zealand has been a comparatively slow adopter of PV technology. However PV in New Zealand is growing rapidly as presented in [2], with the figure doubling in the past two years.

Table 1: Watts per capita of install PV generation as at 2014 (Data from *[3]*)

Country	Watts per Capita
Australia	170
Germany	470
Canada	48
China	21
Finland	2
Hungary	3.8
New Zealand	4[1]
South Africa	17

One of the first issues that is raised about PV generation is its variability, both intra-day at the scale of seconds or minutes, and between days and seasons.

Figure 1 demonstrates the range of daily energy volumes across 2015 in the Canterbury region of New Zealand. The daily energy obtained from 1 Watt of installed PV capacity varies from the maximum of 7.7Wh on 28 December to only 0.36 Wh per W installed on 18 August; a factor of difference of over 21.

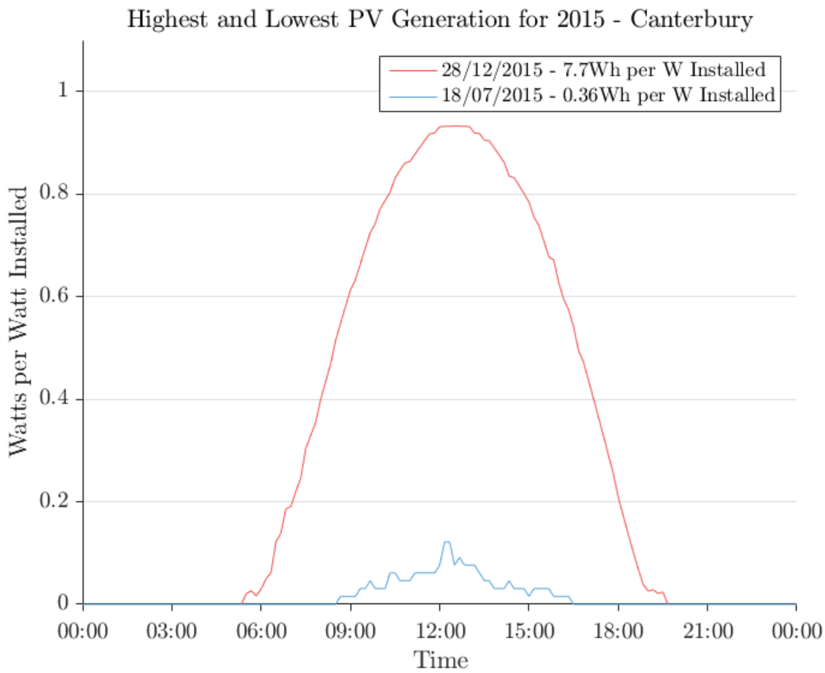

Figure 1: PV generation extrema for 2015 in the Canterbury region

[1] Sourced from EA EMI data as at a comparable time as the rest of the data

Peak Reduction Contribution

It is often said that PV makes no contribution toward reducing peak load. In an annual sense that is correct, the peak system load is in a winter evening when PV makes no contribution, however looking at individual days PV can have a significant impact on daily load peaks.

Three levels of PV penetration were chosen, 8W per capita, 80W per capita, and 470W per capita, corresponding to the current level in New Zealand, ten times the current level representing the potential near future (as little as two years at current growth rates), and Germany's current level as world leader[2].

Canterbury solar irradiance data was superimposed over Orion network loading to create resultant load profiles for each day of 2015. As an example, 6 February 2015 (Waitangi day) is presented in Figure 2. This is the day of 2015 in which PV generation would cause the greatest reduction in the daily peak; 52%.

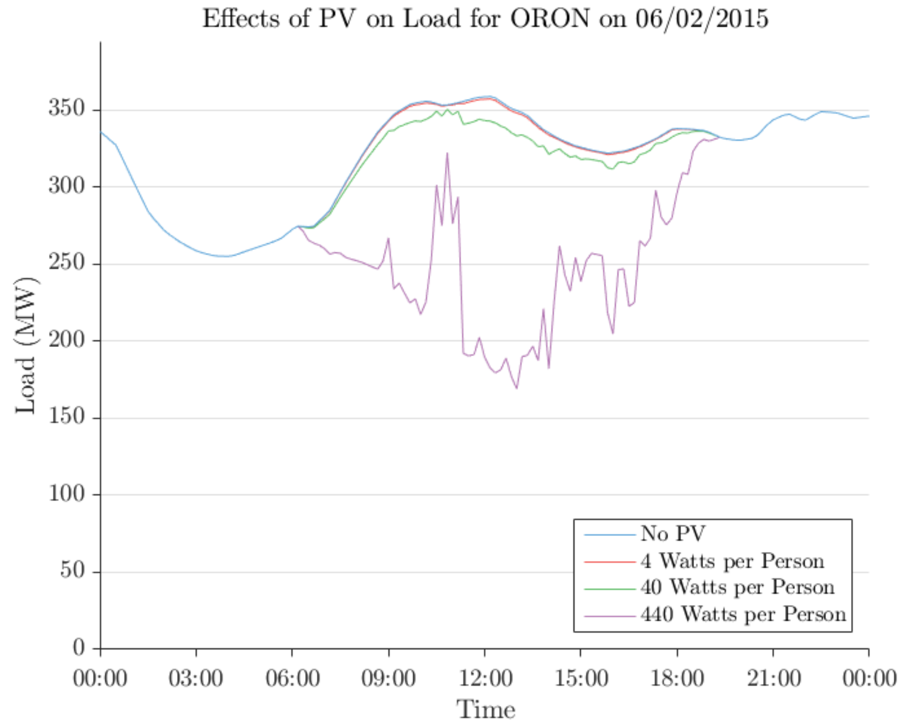

Figure 2: Resultant load profile for Orion on 6 February 2015 with varying levels of PV penetration

For each day the point of maximum load was identified and the reduction in that maximum load which PV generation would provide calculated. These reductions in daily peak load are presented in Figure 3.

[2] Some sources claim Lichtenstein has a higher level of capacity per capita though these figures are disputed amongst sources.

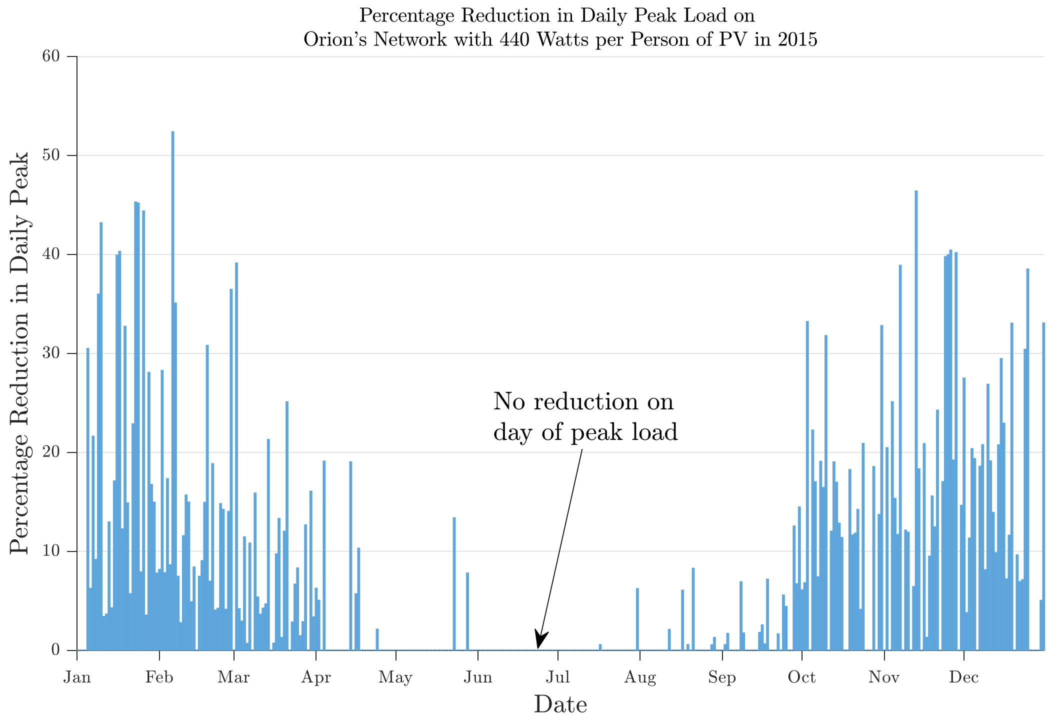

Figure 3: Reduction of daily peaks on Orion's network with 470W per capita installed PV generation

It was found that 470 Watts per capita of installed PV capacity (as in Germany) causes a mean reduction of daily peak on Orion's network of 7.0%. On 144 days of the year the PV generation causes a reduction in peak load >5%. As can be seen in Figure 3 these reductions are almost exclusively in the summer months when not only are sunlight hours longer and solar intensity is higher, but also when the daily peak is less likely to be in the evening. The sudden drop aligns with daylight savings which makes the chance of there being any PV generation at the time of the evening peak even less. Also note that PV makes zero contribution to the highest load of the year in late June.

There is a key assumption here that even with high levels of PV penetration electricity use patterns will remain unchanged. This is an assumption unlikely to remain true given today's tariff structures where self-consumption of distributed generation is economically more sensible than injecting excess generation into the network.

Results have also been calculated for a selection of other EDBs with plans to simulate all other EDBs in the future. The results of these simulations are shown in *Table 2* and Table 3. The daily peaks across a year are on average reduced in the networks, only in half the networks is any reduction experienced during the highest single peak of the year. Future analysis would expand this to look across multiple years.

Table 2: Mean reduction in the daily peaks of 2015

	Mean Reduction in Daily Peak		
Network	**8 Watts per capita**	**80 Watts per Capita**	**470 Watts per Capita**
Orion	0.13%	1.28%	7.5%
Top Energy	0.08%	0.83%	4.87%
NorthPower	0.08%	0.77%	4.54%
Vector	0.25%	2.47%	14.52%
Eastland	0.15%	1.49%	8.77%
Wellington Electricity	0.2%	2.02%	11.89%
Marlborough Lines	0.16%	1.58%	9.28%
Network Tasman	0.20%	1.96%	11.50%
Electricity Ashburton	0.05%	0.49%	2.88%
West Power	0.09%	0.91%	5.32%

Table 3: Reduction in the single largest load of 2015

	Reduction in Annual Peak		
Network	**8 Watts per capita**	**80 Watts per Capita**	**470 Watts per Capita**
Orion	0%	0%	0%
Top Energy	0%	0%	0%
NorthPower	0%	0%	0%
Vector	0.09%	0.88%	5.2%
Eastland	0%	0%	0%
Wellington Electricity	0%	0%	0%
Marlborough Lines	0%	0%	0%
Network Tasman	0.2%	2.1%	12.2%
Electricity Ashburton	0.06%	0.6%	3.6%
West Power	0.1%	1.2%	6.8%

Electric Vehicles

EVs have the potential to create huge changes in demand, not only increasing peak daily demand but also providing enough demand to shift the daily peak temporally. Modelling of EV charging demand is difficult due to it being largely dependent on human behavior. Generally people charge their vehicles either when they arrive home in the evening or later once night rate tariffs have taken effect. As the prevalence of EVs increases it is expected that so too will charging public and business charging infrastructure leading to more charging during the day while their owners are at work.

Electric vehicle numbers in New Zealand are low but growing rapidly. As at March 2016 the Ministry of Transport reports 1128 vehicles in New Zealand's light EV fleet which comprises of both battery EVs and plug-in hybrids. This makes up approximately 0.03% of the total light vehicle fleet [4]. As is shown in Figure 4 the EV fleet doubled in size from January 2015 to January 2016, and is primarily comprised of imported used fully electric vehicles, and new plug-in hybrids. The number of imported used plugin-hybrids is very low.

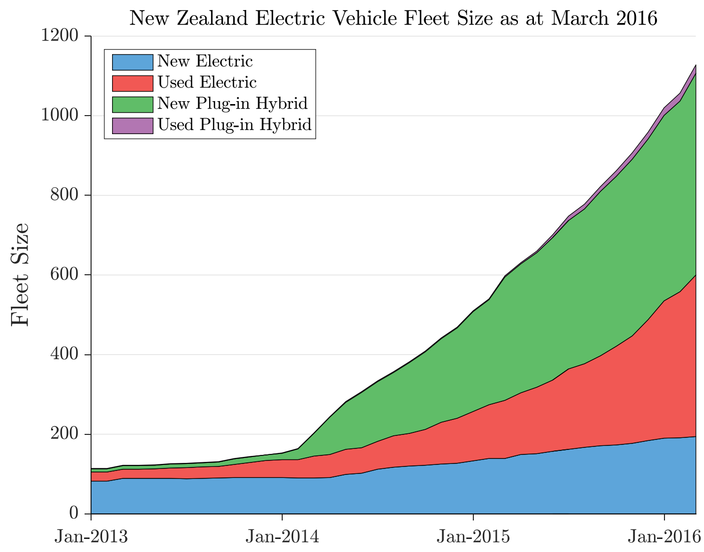

Figure 4: New Zealand Electric Vehicle Fleet Size as at March 2016 (Data from *[4]*).

EV ownership is at its highest in the main centers of Auckland, Wellington, and Christchurch, but is closely followed by Northland and Nelson/Marlborough, as can be seen in Figure 5.

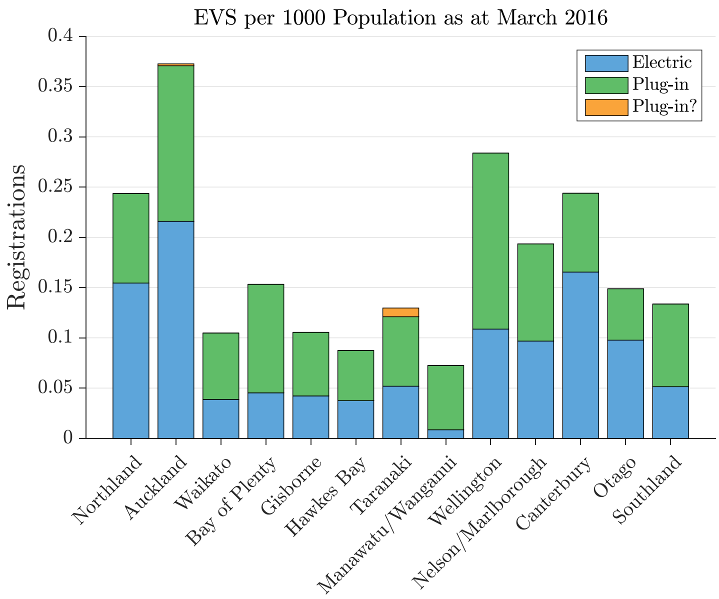

Figure 5: Electric Vehicles per 1000 population as March 2016 (Data from *[4]*).

A model of the load the EV charging would impose upon the network under a variety of circumstances has been built. The inputs are a proportion of the vehicle fleet which is electric, an EDB, and vehicle ownership per capita as obtained from the Ministry of Transport. A probability distribution of charging start times is provided as is the average distance travelled since last charge and the charger size.

Case 1

The first case models the light vehicle fleet being 100% electric using the assumptions in Table 4.

Table 4: EV Charging Load Case 1 Input

Variable	**Value**
Percentage EVs	100%
Network	Orion
Mean daily distance travelled	30 km
Charger size	2.3 kW
Mean charge start time	18:00
Charge start time standard deviation	2 hours

As expected this creates a significant charging load as shown in Figure 6. This is shown superimposed upon the load on Orion's network for the day with the highest average load of 2015. The EVs cause an increase in the peak load of the day by 62% while constituting 14% of the energy delivered in the day. It is clear from observation that opportunity exists through the shifting of charging time and increasing charging diversity to limit the effect of EV charging on the daily peak.

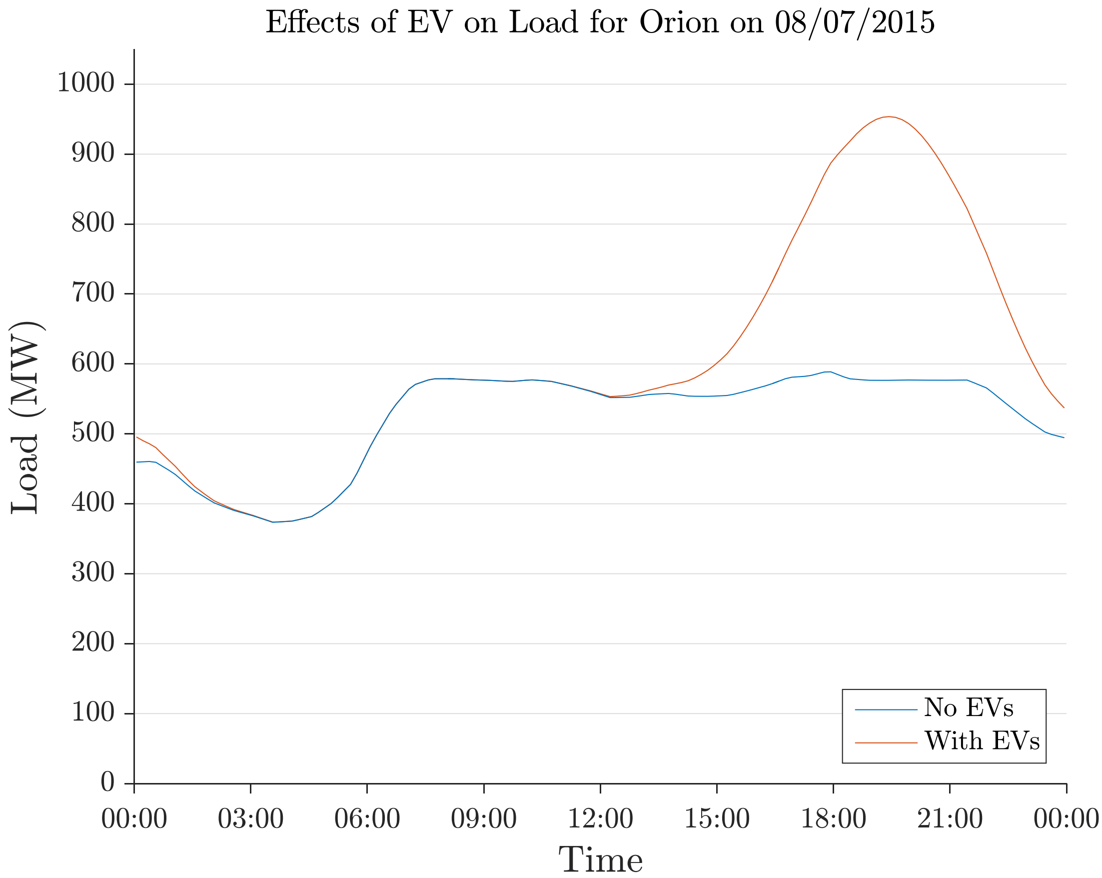

Figure 6: Electric Vehicle Charging Load Case 1

Case 2

100% EVs is beyond the realms of plausibility in the current environment. Consideration must then be given to what a realistic level of EV penetration is. There are many factors which influence the growth of EVs in the light vehicle fleet, many of which are too variable or unknown to be able to create any meaningful prediction of what future growth may look like. Work has been undertaken by others to build a system dynamics model incorporating a number of these factors and allows the use to explore a range of different scenarios [5]. The 'optimistic' scenario which has EVs reaching price parity in two years and no regulatory interventions has EVs making up 20% of fleet purchases within three years. Under this scenario EVs constitute less than 6% of the vehicle fleet in 20 years [6].

A more sensible to model than 100% EVs might then be 10% EVs. Using the same parameters as case 1 but with 10% EV's results in a mean increase in the daily peak across the year of only 4.6% and an average increase in daily energy volumes of 2.3%.

Case 3

Realistically most charging is not going to commence as people arrive home in the evening but is likely to be delayed until night rates take effect. Modifying the mean start time to 11:00pm reduces the mean daily peak increase to only 0.97% while still having all EV charging complete by 6:00am. Figure 7 presents the same day as Figure 6 but with 10% EVs and delayed charging; the effect on the load profile is minimal.

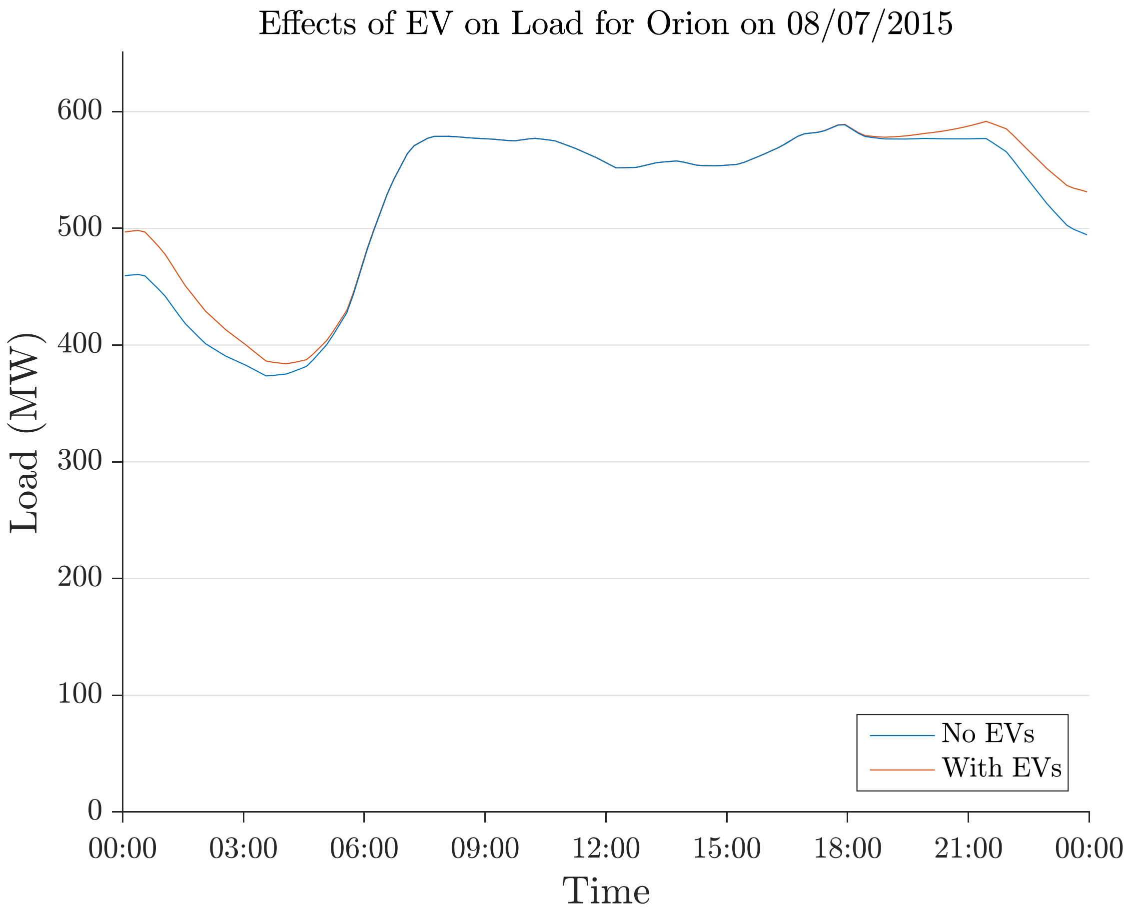

Figure 7: Electric Vehicle Charging Load Case 3

It could be concluded that realistic levels of EV growth over the next 20 years is not likely to cause significant growth in load or load peaks, largely due to the overall fairly low numbers of EVs. As numbers do grow however we expect to see an expansion of public charging infrastructure which will increase charging temporal diversity and reduce overall effects of charging on networks. Future research will examine the effects of EVs on individual feeders and network assets, particularly where EVs may be clustered.

Storage

Home energy storage systems present an interesting idea and raise many questions and possibilities. For households with PV they offer the potential to use day time generation to offset night time grid consumption. For EDBs they offer the potential to reduce system peaks, or minimise reverse power flows due to high distributed generation and low loads. Management of these systems is not just about choosing when to discharge the batteries but equally about when to charge them.

Home energy storage systems have only just started to become a reasonable commercial product and it remains to see the manner in which they will be operated. For the purposes of modelling it has been assumed that network operators have the ability to control the charge and discharge of the batteries; in this case to discharge in a manner so as to reduce the peak of each day as much as possible using the full capacity of the battery (provided the discharge rate of the battery does not cause a constraint), and to charge at a rate and time which provides full charge and causes minimal increase to the system load.

The specifications of the battery system modelled are based upon that of a home storage system released by an international manufacturer of electric vehicles recently. That is a 6.4 kWh discharge capacity and 7kWh charging requirement to account for the published 92.5% round trip energy efficiency. In simulation the charging and discharge rate was capped at the published continuous rating of 2 kW, although the commercial product does have a 3.3 kW peak rating.

As an initial step into the modelling of home energy storage, a scenario was constructed in which the network operator has control of storage systems in 10% of residential ICPs. On Orion's network 10% of ICPs equates to a storage capacity of 107 MWh, which on average across 2015 allows a reduction in the daily peak of 6.8% assuming the batteries are fully discharged.

The level of peak reduction obtainable is constrained by both energy capacity and discharge rate on different days of 2015. If shorter, sharper, peaks are experienced then ability to reduce them is constrained by discharge rate, while for longer flatter peaks energy capacity is the constraint. The influence of duration on peak reduction is illustrated in Figure 8 which shows data from only days apart but with very different load shapes. The first day, with a much peakier load, experiences an 8% reduction in the magnitude of the peak load, while the much flatter load is only reduced by 2.3%.

The effect of a 10% battery penetration level on the overall peak for the year, and daily peaks, for a number of networks is shown in Table 5. As before, analysis has not been completed for all networks in New Zealand, and future work is planned to examine different charging control methodologies.

Figure 8: Comparison of the peak reduction ability of storage given different load shapes

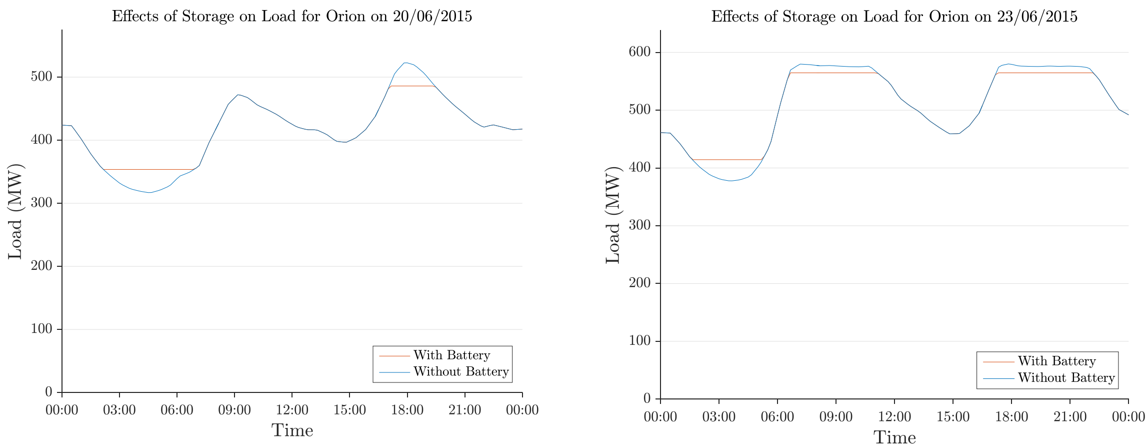

Table 5: Effect of 10% of residential ICPs having battery storage on peak loads

Network	Mean reduction to daily peak	Reduction of the year's peak load
Orion	6.8%	5.9%
Top Energy	9.3%	8.3%
North Power	6.4%	5.4%
Vector	6.9%	5.8%
Eastland	8.5%	8.3%
Wellington Electricity	8.3%	6.1%
Marlborough Lines	7.5%	5.5%
Network Tasman	9.8%	5.0%
Electricity Ashburton	3.8%	1.7%
West Power	11.2%	6.7%

The real interest in home energy storage however is its interplay with photovoltaic generation. Only very initial modelling of this has been undertaken. The scenario modelled is with the same energy storage system as previously, with high levels of PV generation (470 Watts per capita). As an initial model, the batteries charge when there is PV generation and excess PV generation is used to fed into the network. The batteries discharge during periods of highest load. There are some assumptions implicit to this model which will be explored further in future work. The first is that it full knowledge of the entire day's load is known, where in reality charge and discharge decisions are likely to be made in real time with current and historic load known and future forecast loads accounted for. The second day is it is assumed that there is no charge carried over between days (i.e. each day is individually modelled), and batteries are charged only from PV generation. Future work will expand the model flexibility to account for different charging management methodologies. The results, in Table 6, show an increased reduction in peaks with both storage and PV over only storage.

Table 6: Effects of 10% of residential ICPs having battery storage on peak loads with high levels of PV generation in the network

Network	Mean reduction to daily peak	Reduction of the year's peak load
Orion	11.8%	6.1%
Top Energy	12.1%	8.3%
NorthPower	8.9%	5.6%
Vector	17.9%	6.2%
Eastland	15.2%	8.3%
Wellington Electricity	16.5%	6.1%
Marlborough Lines	12.9%	6.4%
Network Tasman	13.9%	10.5%
Electricity Ashburton	5.1%	3.6%
West Power	13.5%	11.7%

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