Establishing the Economic Co-benefits from Aligning Controlled EV Charging and Solar PV Generation in the Australian National Electricity Market

By Graham Mills and Iain MacGill*

The emergence of Electric Vehicles (EVs) represents a historic coupling of the transport and electricity system which for the first time will see private transport energy needs impact electricity system load. In addition, the electricity system itself is going through a period of dramatic change with the emergence of transformative technologies such as solar PV at high penetration levels. Both of these technologies (PV and EVs) have implications for electricity system economics and may represent an opportunity or a threat depending on how they are integrated into the existing system. The challenge for policy makers and the community is to maximise the benefits possible from the emergence of these technologies while avoiding the potential for adverse outcomes.

Key to appreciating how both technologies could be integrated in order to maximise benefits may lie in understanding how their respective characteristics are different but complementary. PV generation is driven by the diurnal solar cycle and therefore lacks inherent temporal flexibility. Given this, beneficial integration of high PV is constrained by the extent to which the underlying power system is able to reduce output to accommodate it while maintaining system security. By contrast, EV charging is fundamentally flexible and able to move across time. The factors which constrain EV charging flexibility however, relate to the temporal and locational alignment between vehicle travel patterns, transport energy requirements, and charging infrastructure availability.

The challenge of high PV penetration is illustrated in Figure 1 a) which shows curtailment should PV generation result in net system load falling below allowable minimum synchronous generation levels. Illustrating the extent to which charging infrastructure availability constrains EV flexibility is Figure 1 b) which presents results from [1] showing the extent to which EV battery energy exceeds that required for reservation against future transport needs. This 'distributed energy resource potential' is clearly enhanced by the availability of non-residential charging infrastructure indicating an enhanced ability to shift charging so as to align with PV generation.

The extent to which EV charging can be aligned with PV generation therefore will rely on 1) management of EV charging behaviour to occur in the middle of the day through incentives or control and is enhanced by 2) the availability of charging infrastructure at high dwell time locations such as workplaces, shopping centres, educational facilities and the like. Should these conditions be met, benefits arising from the interaction between aligned PV generation and EV charging load may be realised in a range of areas including a reduction in: GHG emissions, the cost of generation, PV curtailment, as well as gasoline consumption relative to the case in which EV charging and PV generation are un-aligned or daytime EV charging is constrained by a lack of charging infrastructure availability.

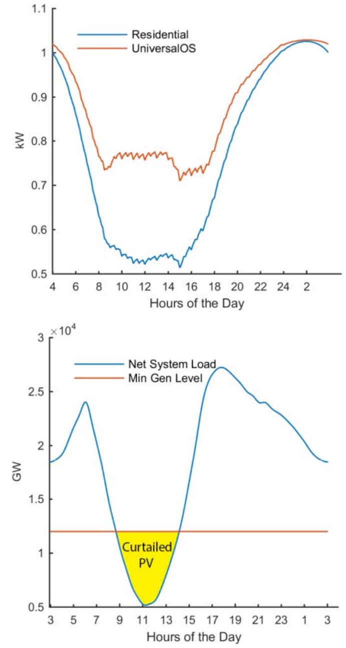

Figure 1 – a) Average sunny autumn day including 25% annual PV penetration by energy and a minimum synchronous generation level corresponding to 35% of peak NEM load; b) Extent to which the SOC of the batteries of connected EVs is excess to the level required for future transport requirements.

This article investigates the co-benefits possible from aligning controlled EV charging with solar PV generation with specific reference to the value of additional non-residential EV charging infrastructure. To illustrate, results are presented from a case study of the Australian National Electricity Market.

Method

A bottom up simulation approach was adopted with the goal of scheduling EV charging during periods of minimum net system load subject to infrastructure and travel constraints. A Plug in Hybrid Electric Vehicle (PHEV) model, approximating a General Motors Volt was used to simulate EV charging and gasoline consumption outcomes. Trip data from the New South Wales Household Transport Survey in respect of 51,800 conventional vehicles was obtained for the Sydney Greater Metropolitan Area and an optimum charging strategy was determined for each vehicle given net system load, travel requirements, and infrastructure availability through the use of a dynamic program. The model scheduled EV charging into periods of minimum system load, specifically the daytime minimum load period which arises with high PV penetrations. Once

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this mid-day minimum net load period becomes dominant, EV charging preferentially fills the 'solar' daytime load valley to the maximum extent possible. Charging requirements then unable to be satisfied during the day occur during the overnight diurnal load valley.

Solar PV penetrations between 10% and 25% of native system energy were assessed for an EV penetration level of 20% of the eastern Australian light duty vehicle fleet with benefits established from applying EV charging load to a simplified generation model of the Australian National Electricity Market (NEM). Generation dispatch in the NEM was then simulated using system load from 2011 with a minimum synchronous load constraint corresponding to 35% of peak load and a carbon price of $20/t CO2. The minimum synchronous load constraint corresponds to the aggregate minimum generation levels of thermal NEM generators dispatched during 2011 and is consistent with [2] who found a similar figure in respect of PJM Interconnection in the United States. Two charging infrastructure availability cases were considered: Residential charging, which involved provided charging infrastructure at any location which was denoted in the NSW HTS as being a residential address; and Universal Off-street (OS) parking which provided charging infrastructure at all residential addresses and parking locations denoted as being off street.

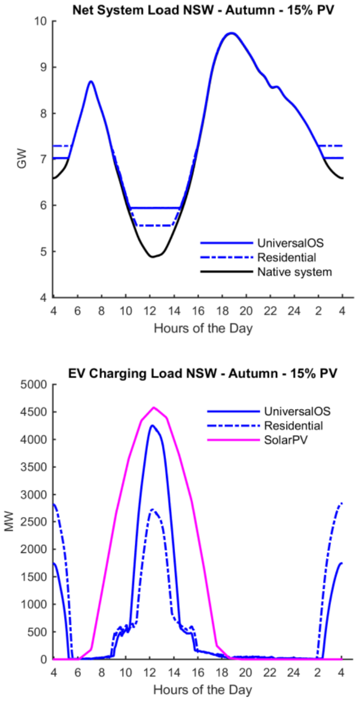

Figure 2 – a) Average autumn day NSW load with 25% PV penetration and controlled charging of an EV fleet of 20% penetration given residential and universal off street EV charging infrastructure; b) corresponding EV fleet charging profile.

Results

In order to demonstrate outcomes for EV charging load under the approach adopted, Figure 2 shows the extent to which EV charging load can be shifted into the middle of an average Autumn weekday under each of the charging infrastructure cases. The increase in daytime charging given non-residential charging infrastructure is clear with the majority of charging occurring during the 'solar' net system load valley. Residential charging infrastructure by contrast sees a majority of charging occur overnight. This difference is reflected by the reduction in curtailed PV which Figure 3 shows to be increased through access to non-residential charging infrastructure. When avoided curtailment is valued at the levelized cost of solar PV reported by the US Energy Information Administration in its 2015 Annual Energy Outlook, $130/MWh [3], the annual financial benefit, relative to the residential only case, is found to exceed $120 million dollars a year at 25% PV penetration.

GHG Emissions and the cost of satisfying EV charging depend on the mix of generators supplying EV load. From Figure 4 it can be seen that the generation mix attributable to EV charging transitions from being overwhelmingly black and brown coal to being majority PV at 25% penetration. While the same general trend is noted in respect of both charging infrastructure cases, the rate at which coal sourced generation declines and PV sourced generation increases is greater with additional charging infrastructure. It should also be noted however, that in the absence of avoided PV curtailment (penetrations rates of 15% or below) EV charging in the Australian NEM results in additional generation sourced from existing, primarily coal, generation sources.

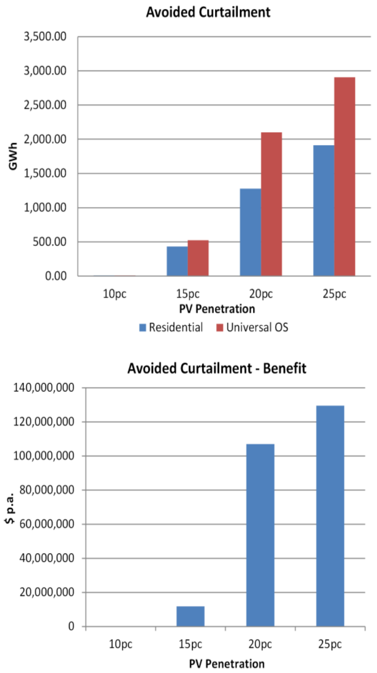

Figure 3 – a) the reduction in annual PV energy curtailment under each EV charging infrastructure case; b) financial benefit from avoided curtailment from the provision of non-residential charging infrastructure relative to the residential charging case.

Combining results in respect of electricity generation and gasoline costs, GHG emissions, avoided PV curtailment allows the total combined benefit achieved by providing additional non-residential charging infrastructure to be assessed. From Figure 5, it can be seen that the total benefit increases as a function of PV penetration rising from slightly under $80 per vehicle per year, to slightly over $140 per vehicle per year. While a net benefit is seen for all penetration levels, electricity system benefits are initially negative and only become significantly positive once PV penetration levels exceed 15%. The largest single contribution is the financial savings is from avoided gasoline consumption attributable to vehicles being able to satisfy a greater proportion of their travel needs from electricity given non-residential charging availability. The benefit associated with avoided PV curtailment also becomes significant at higher PV penetration levels. By contrast, electricity generation and emission cost savings make a much smaller contribution.

Discussion/Conclusion

The results presented here demonstrate the extent to which the provision of non-residential charging infrastructure can enhance the alignment of EV charging and PV generation leading to co-benefits from the integration of EVs and PV at high penetrations. While the benefits identified may be significant, they still only represent a subset of those possible from greater access to EV charging infrastructure. In addition, benefits may also exist in areas such as: avoided generation and network investment costs; energy security benefits associated with reduced oil importation; urban air emission benefits from reduced particulate emissions; and increased EV uptake through a reduction in range anxiety.

While benefits exist, the provision of non-residential charging infrastructure also faces a number of barriers which create a case for public policy intervention. It has been found that revenues from the sale of electricity are in-sufficient to support a viable independent business model for non-residential EV charging [4]. This situation creates the potential for market failure due to the external benefits accruing to all parties and members of the community not being reflected in the private benefit realised by an independent investor relying on revenues from the sale of electricity. These 'external' benefits accrue to a range of parties other than the investor such as non-priced benefits for the the electricity system; a reduction in the social costs associated with climate change; benefits to vehicle manufacturers through an increase in the rate of EV adoption; benefits to individual drivers, and society, from reduction in gasoline consumption; as well as benefits for PV investors through a reduction in levels of future PV curtailment. Such market failure can be expected to result in suboptimal investment levels and inefficiently foregone benefits for society.

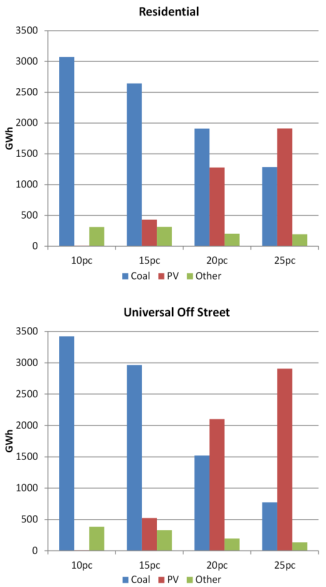

Figure 4 – a) Source of generation attributable to EV charging given residential charging infrastructure; b) Source of generation attributable to EV charging given residential and universal off street charging infrastructure.

In addition to the presence of positive externalities in a general sense, a specific case of market failure impacting non-residential charging infrastructure deployment is that of the tenant landlord problem. The tenant landlord problem relates to the situation where one party (either the tenant or landlord) is unwilling to make an investment the benefits of which will accrue to the other party. The tenant landlord problem was investigated by [5] who found that one of the principle barriers to EV charging infrastructure investment in multi-unit developments in the Los Angeles area was determining whether the building owner, or tenant was responsible for paying for the equipment and installation costs given that the residual value would pass to the building owner at the end of the tenancy period. The presence of such market failures therefore require policy solutions which are not only limited to financial support, but also include legal and contractual frameworks which reduce the transaction costs created due to negotiations between parties.

This article presented results form a case study involving a single vehicle battery size, assessed using vehicle travel information from a conventional vehicle fleet, with benefits established in respect of the thermal coal heavy existing Australian NEM. Both EV battery sizes and the physical electricity generation system can be expected to change over the period during which EV and PV penetrations become significant. Therefore, care should be taken in generalising the findings presented here. Instead, these results should be viewed as creating a case for the development of public policy to encourage efficient long term investment in non-residential charging infrastructure rather than a definitive and predictive assessment of future outcomes.

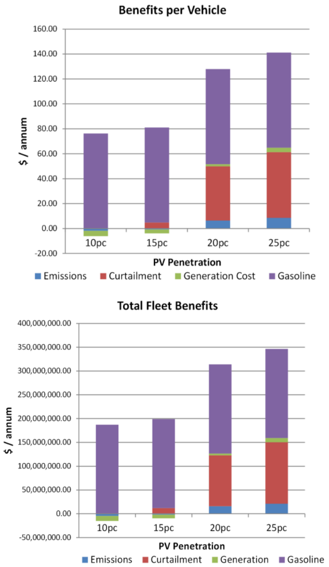

Figure 5 – a) Total combined benefits for an average vehicle due to the provision of residential and universal off street charging infrastructure relative to residential infrastructure; b) Total combined benefits in respect of the provision of residential and universal off street charging infrastructure relative to residential infrastructure for a 20% NEM state light duty vehicle fleet.

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