Genetration investment requirements, generation costs, and GHG emissions from Plug In Hybrid Electric Vehicle charging control in the Australian National Electricity Market

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Overview

Electric vehicles (EVs) represent a potentially transformational technology leading to the convergence of private transport and the electricity industry. This convergence has the potential to create economic value for society through a variety of benefits including savings from the substitution of gasoline for electricity, a reduction in external costs associated with greenhouse gas (GHG) emissions, as well more efficient electricity industry operation and investment [1]. The extent of these benefits however, are a function of a set of uncertain variables relating to the manner in which EVs are integrated into the existing electricity system. In particular the temporal characteristics of electric vehicle charging load will determine the resulting costs and GHG emissions which arise from servicing that load [2].

Efforts by the electricity industry to manage the timing of EV charging have involved incentivising drivers to charge during offpeak periods. Such incentives include offering time of use (ToU) electricity tariffs. Simple ToU tariffs however create the potential for highly co-incident charging which may to create negative outcomes at high penetration levels [2]. Another approach may be to optimally schedule charging to fill the overnight demand valley. Such scheduling may avoid probems from co-incident vehicle charging but come at the expense of higher GHG emissions and gasoline consumption. This paper investigates the benefits, or costs, associated with ToU and controlled overnight charging relative to un-managed EV charging in the Australian National Elecgtricity Market over the period to 2037. Investigations will focus on electricity generation investment requirements, energy (electricity and gasoline) costs, and GHG emissions. This paper represents the first occasion on which such outcomes have been investigated for the NEM using a long term electricity planning model. Results are intended to inform policy makers with respect to the tradeoffs between these different approaches to influencing the temporal characteristics of EV charging.

Methods

This study utilizes vehicle trip information from the Australian state of NSW Household Transport Survey (NSW HTS) in respect of travel by 51,800 vehicles in the Sydney Greater Metropolitan Area over the period 2002-10 [3]. Charging in response to NSW HTS travel patterns was simulated using a Plug in Hybrid vehicle approximating a General Motors Volt with charge sustaining mode energy consumption of 0.17 kWh/km (0.27 kWh/mi) [2] and gasoline consumption while in charge sustaining mode of 15.7 km/L [5]. The timing of vehicle charging in response to trip behavior, the availability of charging infrastructure, and charging control signal was established for each HTS vehicle by identifying the lowest ‘cost’ charging strategy via dynamic program [6]. The dynamic program used an objective of minimising either the financial cost of charging (in the ToU case) or total system demand in the overnight charging case. Constraints include the requirement to commence and end each day with a full battery and charge only at locations denoted has having charging infrastructure (residential locations). A simple three level (offpeak, shoulder, and on peak) ToU electricity tariff was applied reflecting those available for households in NSW.

Simulated EV charging load was then scaled using a logistic function (r = 0.35) to reflect a saturation EV penetration of approximately 45% of the 2012 NEM state light duty passenger vehicle fleet by 2050. Results to 2037, the time hoirizon of interest, were then added to the system load projections (50% probability of exceedance) published by the Australian Energy Market Operator (AEMO) as part of its 2012 National Transmission Network Development Plan (NTNDP) [7]. Electricity generation investment, dispatch, and emissions over the period to 2037 were then obtained using this load profile from the long term expansion module of electricity market simulation platform PLEXOS for Power Systems.

PLEXOS is a commercially available electricity market simulation platform developed by Energy Exemplar. PLEXOS applies Linear Programming (LP) and Mixed Integer Programming (MIP) methods to produce forward price, investment, and dispatch outcomes in a manner similar the SPD (scheduling, pricing and dispatch) engine used by AEMO to operate the NEM [8]. PLEXOS finds the optimal combination of generation new builds and retirements that minimizes the net present value (NPV) of the total system costs over a long-term planning horizon by simultaneously solving a capacity expansion problem and a dispatch problem from a central planning, long-term perspective.

Results

Results are obtained for each year over the investment horizon to 2037 with respect to the 1) Difference in lowest cost generation investment requirements 2) Difference in electricity generation costs 3) Difference in GHG emissions between cases. Initial results show a significant increase in additional generation investment requirements (particularly gas) associated with the implementation of ToU tariffs with high EV penetration rates. Such an outcome reflects the additional peaking generator investment required to satisfy the highly co-incident charging peaks occurring once EV charging load becomes responsible for the system peak. Conversely, the overnight valley filling case sees no increase in generation investment requirements but an increase in GHG emissions. Such an increase in emissions reflects the baseload generation mix in the NEM which is dominated by black and brown coal.

Conclusions

The broader policy challenge is to ensure a set of arrangements which satisfies end user transport needs at the lowest cost to the power system. While the benefits associated with a reduction in investment requirements through valley filling overnight charging outweigh the costs of higher GHG emissions, such tradeoffs illustrate the need to transition the NEM generation system away from a dependence on coal in order for EVs to represent a source of GHG abatement. Simple ToU electricity tariffs represent a reasonable first step in incentivising off peak charging, they represent an inappropriate mechanism for high future penetration levels.

References

[1] M. Kezunovic, S. T. Waller, and I. Damnjanovic, "Framework for Studying Emerging Policy Issues Associated with PHEVs in Managing Coupled Power and Transportation Systems," in *Green Technologies Conference, 2010 IEEE*, 2010, pp. 1-8.

[2] G. Mills and I. MacGill, "Potential power system and fuel consumption impacts of plug in hybrid vehicle charging using Australian National Electricity Market load profiles and transportation survey data," *Electric Power Systems Research*, vol. 116, pp. 1-11, 2014.

[3] NSW Bureau of Transport Statistics, "Household Travel Survey," 2012.

[4] T. Markel and K. Wipke, "Modeling grid-connected hybrid electric vehicles using ADVISOR," in *Applications and Advances, 2001. The Sixteenth Annual Battery Conference on*, 2001, pp. 23-29.

[5] www.fueleconomy.gov. (2013). *2013 Chevrolet Volt Fuel Economy*. Available: http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=32655

[6] O. Sundstrom and L. Guzzella, "A generic dynamic programming Matlab function," in *Control Applications, (CCA) & Intelligent Control, (ISIC), 2009 IEEE*, 2009, pp. 1625-1630.

[7] Australian Energy Market Operator. (2012). *National Transmission Network Development Plan - Consolidated 2012 Plant Technical Data*. Available: http://www.aemo.com.au/Electricity/Planning/National-Transmission-Network-Development-Plan/Assumptions-and-Inputs

[8] L. Wagner and L. Reedman, "Modeling the deployment of plug-in hybrid and electric vehicles and their effects on the Australian National Electricity Market," in *Innovative Technologies for an Efficient and Reliable Electricity Supply (CITRES), 2010 IEEE Conference on*, 2010, pp. 165-170.