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V2G and G2V role in Demand Response: A Southern California Case Study

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Summary

In this project we modeled the Los Angeles power grid and optimized the grid interaction of electric vehicles (EVs) for the year 2020, such that battery capacities in EVs can be used efficiently for grid interaction. For this purpose, a demand driven optimization model was developed based on an hourly distribution of vehicle miles travelled. We assume that any parked, plugged EV can interact with the grid. Optimal vehicle-to-grid (V2G) and grid-to-vehicle (G2V) energy flows are calculated based on various factors, such as battery capacity, charging and discharging rates, required energy for driving demand, hourly electricity price, and ramp-up constraints. Based on these calculations, in our base case scenario of EV adoption, using EV batteries in parked EVs through a smart grid network can help flatten the net daily load (reducing the "duck curve") by using mid-day solar energy and then providing power for peak load.

Keywords: Electric Vehicles, Grid Interaction, Renewable Energy Penetration, Demand Response

1 Introduction

California's Renewable Portfolio Standard goals call for significant expansion of renewable electricity (e.g., wind and solar). This means a higher share of variable electricity generation that does not necessarily coincide with time of demand (i.e., is not dispatchable), as illustrated in Fig. 1. During midday and early afternoon, the supply of solar energy is high (green curve), but load is relatively low. Then, in the evening, solar energy production is low, but load ramps up. As a result, the net load—the total load in the system minus available solar energy—decreases in the afternoon and rises sharply in the evening. Thus, this net load, which represents electricity produced by nonrenewable sources, follows the duck curve when graphed over a 24-hour cycle (orange curve). The midday dip in the duck curve is deeper in the spring than in the summer or winter, because in the spring the load during the day is lower due to less need for air conditioning or heating. The lower midday load in spring results in a correspondingly lower midday net load.

The duck curve is expected to become more extreme as solar energy harvesting increases in California. Due to limited storage capacity, utility companies must curtail renewable power at its peak productivity in the middle of the day, hindering the ability to reach renewable power goals. Could distributed energy storage in EVs be used to soften the mismatch between demand and supply, by having parked EVs charge primarily at noon/early afternoon and then recharge the grid in the evening, when electricity demand and prices are highest? What would the optimal distributed capacity expansion be in the Los Angeles area? What are the challenges in this strategy, given patterns of operation and charging of EVs? What policies might be needed to create an economically viable system for V2G integration in California's energy system and enable an optimized demand response?

We evaluated changes in net load in a system with solar energy combined with forecasted numbers of EVs that would be used for distributed storage. The benefits of such a strategy may include providing low-cost zero-carbon fuel for fuel cell electric vehicles (FCEVs), zero-carbon industrial feedstock, and flexible supply and energy storage for the grid.

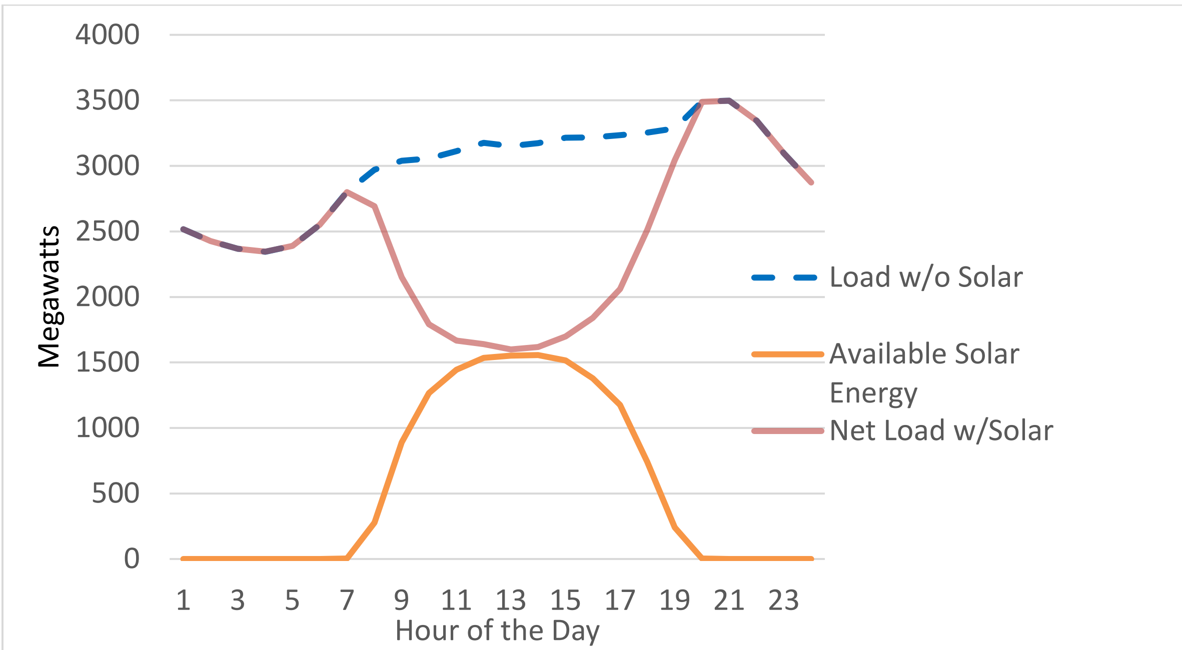

Figure 1. Actual duck curve shown in orange, representing data from March 27, 2017 in Los Angeles Department of Water and Power territory. The net load (orange) represents the load without solar energy (dotted blue) minus the available solar energy (green).

2 Methodology

The model is a technoeconomic optimization model developed base on the widely used MESSAGE (Model for Energy Supply Strategies and their General Environmental Impacts) platform. It optimizes the energy system employing a mixed-integer demand driven mathematical model. California electricity supply chain from generation, transmission, distribution and all the way to end-use sectors is incorporated into the model. It not only serves as a dispatch model for the electricity system, but also long-term capacity expansion planning including charging stations, storage systems and electrolysis plants.

We created scenarios using future penetration of EVs into Southern California and optimally controlling the V2G and G2V time-of-day usage in accordance with people's daily use pattern. This analysis uses a grid operation optimization for one year at an hourly step. We created a technoeconomic optimization model, called CalEV.

CalEV optimizes the system employing a mixed-integer mathematical model. Our model simulates a smart grid, where the interaction between EVs and the grid is optimized based on different technoeconomic factors, such as pricing, travel demand, and electricity supply.

In the CalEV model, the first priority of energy stored in the EV is for driving, and the second is for return to the grid. Once parked, if there is excess battery energy (i.e., more than either 30% and the amount needed for a daily trip) and the pricing is right, energy will be supplied from the EV to the grid. In other words, there is a constraint in the optimization model to keep the state of charge (SOC) in each battery above 30% at all times, for emergency need. Also, the batteries will be charged up to 80% of full capacity to enable a faster charging rate with a near linear characteristic.

2.1 Selection of Input Data and Modeling Assumptions

Load and solar energy inputs for the CalEV model were actual data from March 27, 2017 in the Los Angeles Department of Water and Power (LADWP) territory. (These data exhibit the duck curve in Figures 1 and 3.) March 27, 2017 was chosen because it was: (1) in spring, when the duck curve is more extreme; and (2) a Monday, when VMT data would be representative of a weekday. The hourly VMT distribution was processed from the EPA MOVES model and incorporated as travel demand in the CalEV optimization model. According to the LADWP Transportation Electrification Plan, 127,000 EVs are forecasted to be in Los Angeles in its base case scenario for the year 2020. Based on the assumption of 35 mile/day average vehicle travel in LA (Caltrans and Statista websites),[5,6] there would be an average of 4,551,657 eVMT in any single day. According to a report from the National Renewable Energy Laboratory, a battery electric vehicle with 100-mile range (BEV100) consumes 0.325 kWh/mi, which results in 1,479,288 kWh energy required for all EVs in Los Angeles for a typical day in 2020. Average BEV battery capacity was assumed to be 50 kWh for 2020.

3 Results

Fig. 2 and Fig. 3 show the results for an optimized solution for V2G and G2V during the 24 hours of March 27, 2017, based on travel demand and vehicle availability to the grid. Fig. 2 shows the distribution of hourly VMT of EVs in purple. When more vehicles are on the road, fewer are parked and therefore connected to the grid. We assume that any parked EV is connected to the grid and can have grid interactions (all parking spots have charger access). In Fig. 2, the flow of energy from batteries to grid (V2G) is represented by orange bars and from grid to batteries (G2V), by blue bars. The amount of energy in the battery (i.e., SOC) is shown with grey bars.

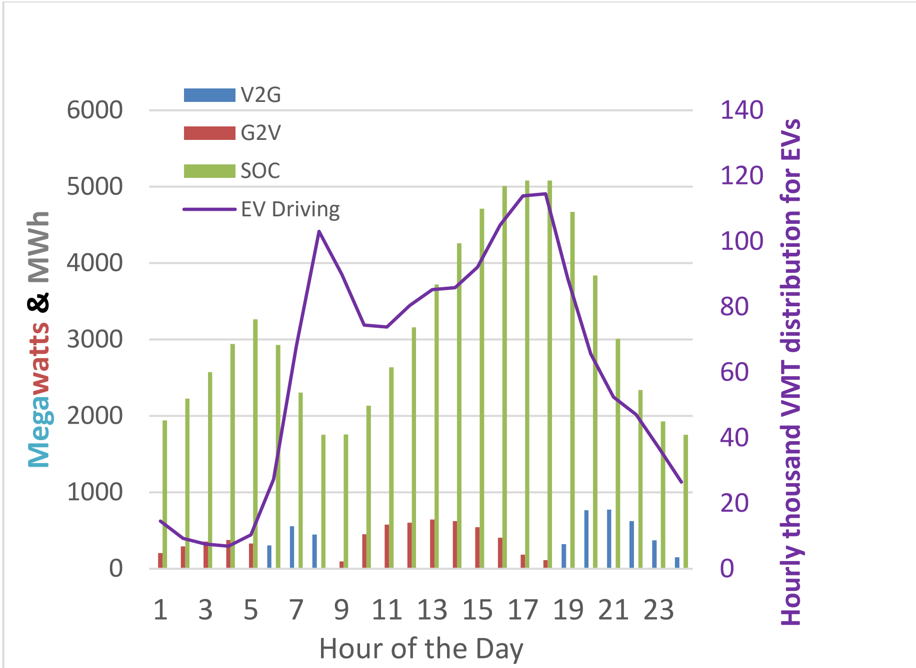

Figure 2. Left axis and bar graph: Plot of energy transferred between grid and vehicles (in megawatts) and the state of charge (SOC; in MWh). SOC is optimized between 30% and 80% of battery capacity and total net difference of G2V and V2G during the day equals total eVMT electricity requirement for all the vehicles. Right axis and purple curve: Distribution of VMT by EVs throughout the day.

In Fig. 3, the orange (duck) curve represents the actual net load on March 27, 2017, without system optimization—i.e., without considering the effects of V2G or G2V. When V2G and G2V are added, the "Load w/o Solar" grey dotted curve results. (For comparison, the blue dotted curve in Fig. 1 is the load without solar in 2017 when there is no V2G or G2V integration.) As shown in

Fig. 3, when V2G and G2V are optimized and incorporated into the model, the net load curve, originally a duck curve (dotted orange), is flattened out (solid orange). This optimization for an actual hourly supply and demand in Los Angeles for a day in Spring 2020 shows that a smart grid V2G and G2V system can reduce the difference between minimum and maximum net load for any given day, from 1.9GW without EVs (Fig. 1) to only 500kW with EVs (Fig. 3). Optimization reduces the peak load from 3,500 MW to 2,700 MW (about 800 MW), which is a considerable amount that can reduce the need for expensive capacity expansion and contribute to the stability of electricity prices, helping to justify the expenses associated with V2G uptake incentives.

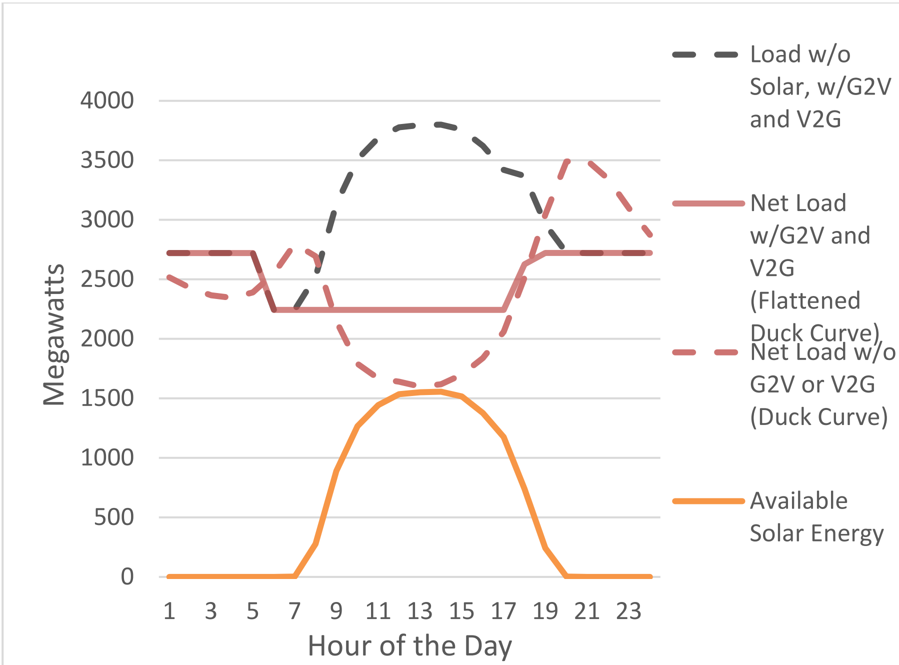

Figure 3. Optimized results for a smart grid V2G and G2V connection to the grid showing that the duck curve (dotted orange) flattens out (solid orange) by utilizing the EV battery capacity throughout the day.

Fig. 4 shows the state-of-charge pattern, along with charging and discharging, of all EVs in two scenario runs. The left graph shows the optimal operation of grid when only V1G is allowed. The right graph shows the optimal V2G and G2V interaction. As shown, in order to meet daily driving need, only 11.6kWh per vehicle energy is required which is a small fraction of total battery capacity. As V2G is allowed, more battery storage would be utilized to manage the grid load which still would be utilizing only 50% of the battery capacity for this purpose.

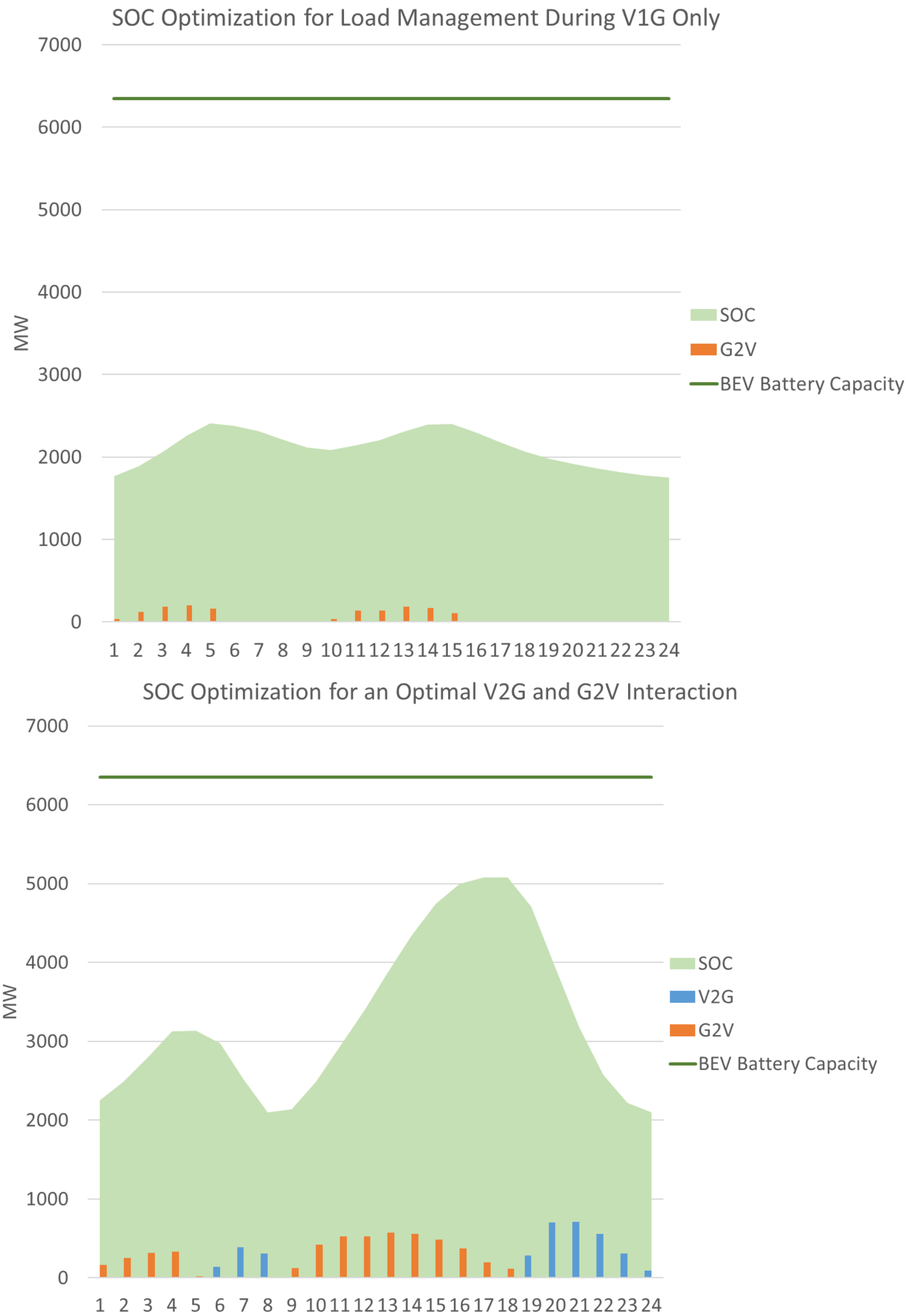

Figure 4. Effect of V1G and V2G on utilizing more battery capacity for VGI purposes

4 Conclusions

It is concluded that even with a moderate EV adoption plan (127,000 EVs by 2020, equivalent to an increase of EV adoption to only 13% of vehicle purchases), there will be a sufficiently large EV battery storage capacity available to utilities to significantly assist with peak load shifting and flattening of the duck curve. This grid simulation indicates that although there might be additional constraints that can affect the vehicle availability to the grid—such as availability of charging stations, willingness of EV owners to participate in a grid interaction program, costs associated with V2G investments and charging infrastructure—the potential impact of EV storage on the grid warrants continued development and investigation of this option. Over time, the potential impact should continue to increase as more EVs are used.

Also, a scenario with only charging management of the BEVs (V1G) was compared with two-way flow of G2V and V2G for grid interaction purposes. In order to meet daily driving need, only an average of 11.6kWh per vehicle energy is required which is a small fraction of total battery capacity. When V2G is allowed, much more battery storage would be available and utilized to manage the grid load. This result is obtained by assuming that only 50% of the battery capacity is available for grid interaction purposes.

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