Residential Charging Behavior in Response to Utility Experimental Rates in San Diego

April 2015

Key Conclusions

- The EV Project and the San Diego Gas and Electric (SDG&E) experimental rate study confirm that price incentives can substantially influence Plug-in Electric Vehicle (PEV) driver residential charging behavior.
- The SDG&E rate study showed that the greater the differential electrical price between utility non-desired charge time and its desired charge time, the greater the behavioral change in driver residential charging.
- The cost of installation of a second electric utility meter, required by many utilities for their special PEV charging rates, may exclude many drivers from participating.
- Participation in electric utility incentive programs requires not only the considered design of electric rate structures but also requires the enabling technology to set charge start times either by the residential electric vehicle supply equipment (EVSE) or the PEV. It may also require the EVSE or PEV to communicate billing information to the utility for subtractive billing.

Introduction

The EV Project enrolled over 8,000 residential participants. These participants purchased or leased a Nissan Leaf or Chevrolet Volt and the Blink Electric Vehicle Supply Equipment (EVSE), used to recharge the Plug-in Electric Vehicle (PEV), was installed by The EV Project at their residences. The power required to recharge all PEVs in a region can be a significant electrical load on the electric grid. Certain electric utilities within the EV Project regions incentivized The EV Project participants to charge their PEV at specific times to shift the load on the grid from PEV charging to off-peak periods on electrical system. Reference 1 explored the results of the incentives in several regions of The EV Project. It observed that financial incentives successfully shifted PEV charging demand to off-peak hours.

While it was shown that time-of-use (TOU) rates can influence charging behavior, SDG&E (one of the electric utilities providing TOU rates) desired to know what magnitude of pricing differential between the peak and off-peak rates was required to drive participant behavior to charge in off-peak times. With the approval of the California Public Utilities Commission (CPUC), SDG&E established three experimental rates and designed the Plug-in Electric Vehicle TOU Pricing and Technology Study (Study) to run concurrent with the EV Project deployment of PEVs in the San Diego region. Most of the participants enrolled in the EV Project in San Diego who purchased or leased the Leaf became participants in the Study. The final evaluation of the Study, as provided to SDG&E by Nexant, is provided by Reference 2. This paper provides the EV Project perspective on the Study.

Experimental Rate Design

At the start of The EV Project, SDG&E had two PEV TOU rates: the EV-TOU schedule applied to those who installed a electric utility meter to monitor the PEV charging separate from the household loads, and the EV-TOU-2 schedule applied to those who did not install a separate meter but relied on the existing whole house meter to monitor all loads.

The Study intended that the EV Project participants driving the Leaf in the San Diego region would be randomly assigned one of three experimental TOU rates. These rates required a second meter for monitoring the PEV charging, the expense to install this meter were paid by SDG&E in conjunction with the installation credit provided by The EV Project.

The Study required that the participant be enrolled in The EV Project, that they owned or leased the Nissan Leaf, that they had the separate utility meter installed to monitor PEV charging, that they be randomly assigned one of the experimental rates, and they agreed to participate in the Study. The second meter specifically monitored PEV charging so it would not be included in the energy used by the whole house and could be priced separately. At the end of the Study, the participant would be able to select an existing TOU rate schedule.

The experimental rates as approved by the CPUC are identified in Reference 3. It followed the same design as the EV-TOU-2 schedule in providing for on-peak, off-peak, and super off-peak pricing by time of day. The original EV-TOU-2 schedule is shown in Figure 1.

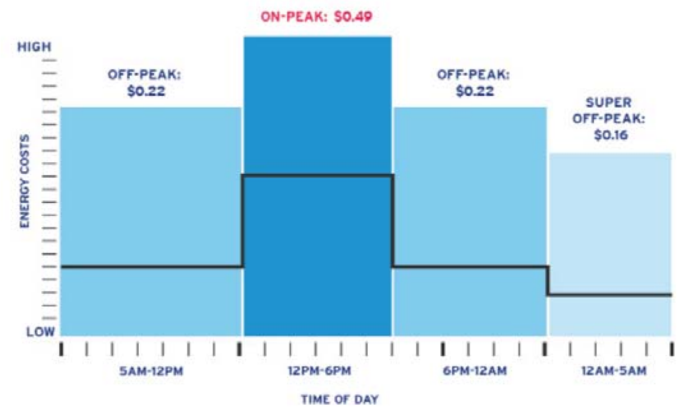

Figure 1. SDG&E EV-TOU-2 summer schedule[4].

The EV-TOU rate design is similar except that the on-peak time is from noon to 8 p.m. rather than noon to 6 p.m. of the EV-TOU-2 schedule. This rate design provides an approximate 3:1 ratio between the on-peak rate and the super off-peak rate. While this rate design provides a financial incentive to the PEV driver to charge during the off-peak and especially the super off-peak times, the driver still has the option to charge at any time of the day. The Study's experimental rates were established using three different ratios between the on-peak and super off-peak rates; approximately 2:1 (the EPEV-L schedule), 4:1 (the EPEV-M schedule), and 6:1 (the EPEV-H schedule), allowing SDG&E to determine the magnitude of price difference necessary to drive participant charging behavior to super off-peak times. Figure A-1 in Appendix A provides the summer period comparisons of these rates and illustrates that all the experimental rates are lower than the EV-TOU and EV-TOU-2 rates.

The EV Project installed Blink EVSE in the homes of each of its participants in the San Diego area. The Blink EVSE provides an intuitive touch screen interface allowing the PEV owner to easily schedule a window of time during which the EVSE will provide charge power, allowing the PEV owner to schedule charging to take advantage of the SDG&E off peak and super off peak rates.

EV Project Analyses

The Blink EVSE allows The EV Project to collect EVSE usage data. Each EV Project participant gave written consent for EV Project researchers to collect and analyze data from their vehicles and EVSE. Charge data was transmitted by the Blink EVSE was collected by the Blink network and subsequently transmittal to the Advanced Vehicle Testing Activity of the Idaho National Laboratory (INL). INL's data experts then qualified and aggregated data for reporting.

The EV Project published quarterly reports on this aggregated data which are available on the INL website: http://avt.inl.gov/evproject.shtml.

Understanding PEV driver charging behavior involves an evaluation of both "Charging Availability" and "Charging Demand".

Charging availability at a point in time is defined as the percentage of EVSE in a geographic area that are connected to a vehicle. While the EVSE may be connected to the vehicle, it may not necessarily be charging. Charging demand at a point in time is the total amount of power being drawn from the electric grid by a group of EVSE in a geographic area. These are represented by time-of-day plots. The quarterly reports prepare these plots by geographic area and show the hourly percentage of EVSE connected and hourly charging demand for all weekdays and weekends for the quarter evaluated.

Figure 2 shows the weekday residential charging *availability* for EV Project vehicles in the SDG&E service territory during the second quarter 2013. Figure 3 shows the weekday residential charging *demand* in the SDG&E service territory for the same time period. Note that the plot shows the maximum, minimum, median, and inner quartile values for all the days in the quarter. With all this data plotted on the same time-of-day scale, it is clear that while PEV drivers typically connect their PEVs when returning home, the start of the charge is typically delayed until after the start of the super off-peak period of midnight.

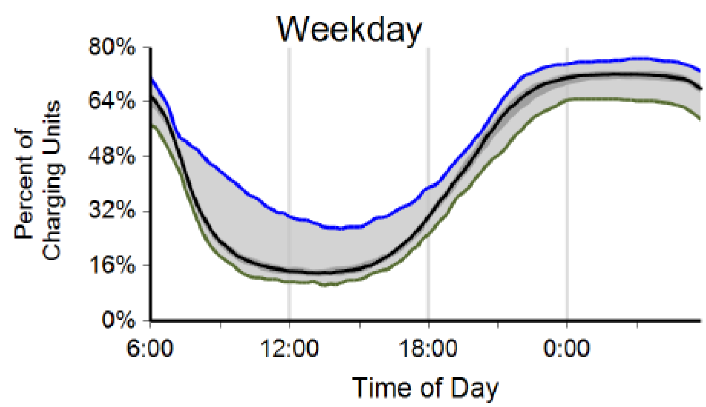

Figure 2. Weekday residential charging availability San Diego Q2, 2013[5].

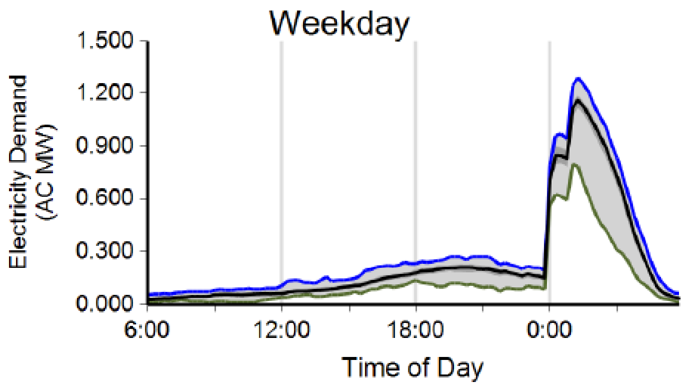

Figure 3. Weekday residential charging demand San Diego Q2, 2013[5].

As The EV Project achieved full participant enrollment in early 2013, Figures 2 and 3 illustrate well established behavior by the participants. Even though charging predominately occurred during the super off-peak times, there was residential charging occurring during the on-peak and off-peak times in spite of the pricing incentives of the Study.

Discussion of Study Results

Reference 2 reported that 430 of the 700 EV Project participants in the San Diego region agreed to participate in the Study and 272 were enrolled in the EV-TOU-2 (whole house) rate. A variety of reasons were provided for those electing not to participate including "…problems with configuration of their home, installation costs that exceeded the installation allowance offered by the EV Project or a desire to not be placed on an experimental rate." One of the configuration issues involved the existing electrical service entrance to the residence. Installing a second meter can be quite costly for some configurations, particularly when the electric service is provided by an underground connection.

The Study provided several key findings[6]:

Key Finding 1: Participant EV Charging Takes Place Mostly During the Super Off-peak Period Using Charging Timers

"…EPEV-H and EPEV-M customers had the highest percent of total charging done during the super off-peak period (85% and 83%, respectively), while EPEV-L customers had 78% of all charging done during the super off-peak period (78%)."

Key Finding 2: Participant EV Charging Exhibit Learning Behavior

"During the first four months of participation in the Study, customers in the EPEV-L and EPEV-M rate groups increased their share of super off-peak charging and decreased their share of peak period charging, a trend seen for both weekday and weekends. In contrast, EPEV-H customers generally exhibited consistent charging behavior for the entire duration of the Study."

Key Finding 3: Participant EV Charging Behavior Responds to Price Signals

"Formal hypothesis tests show that providing stronger price signals to customers causes them to charge relatively more during super off-peak hours and charge less during the on-peak period on both weekdays and weekends… Compared to the EPEV-L rate with the smallest price ratio, the EPEV-M rate increased the share of weekday charging during the super off-peak period by 4 percentage points and reduced the share of peak period charging by 2 percentage points. The EPEV-H rate had a larger effect, increasing the super off-peak charging share by about 6 percentage points and reducing the peak charging share by 3 percentage points relative to the EPEV-L rate. "

Key Finding 4: EV Customers Are Most Responsive to Changes in On-Peak and Off-peak Prices

"In order to apply findings from this Study to future electric vehicle charging rates or to EV rates in other regions, a structural economic model of charging behavior was used to explicitly capture the trade-offs associated with charging during one period versus another and provide estimates of price elasticities for EV charging." See Reference 2 for specific findings in this area however, two are repeated here:

- Study participants are more responsive to changes in either the peak or off-peak price than to a change in the super off-peak price;
- Simulations of EV charging behavior under TOU rates with other price ratios suggest that a price ratio of 6:1 between peak and super off-peak periods would result in customers using about 90% of their electricity for EV charging during the super off-peak period and that further increases would provide only marginal additional increases in this percentage.

"The primary conclusion from the Study is that TOU prices in conjunction with enabling technology, such as the on-board LEAF charging timer or the timer in the charging unit, results in the vast majority of EV customers charging overnight and in the early morning rather than during on-peak times. A large body of evidence suggests that the simple enabling technology of charging timers make it easy and convenient to charge overnight so that a strong tendency for overnight charging is induced by a small rate differential."

The report notes that "…all data analyzed here represent the behavior and choices of customers who are early adopters of a new technology… the extent to which the charging behavior of early adopters represents the behavior of customers who adopt EVs over a longer time horizon is unclear."

The report also states, "SDG&E also offers an electric vehicle TOU rate (EV-TOU) that, like the experimental rates, applies to only the EV load and usage. This rate requires customers to install a separate parallel meter and is rarely chosen."

The Study ended in December 2013 and participants were enrolled in the previously existing rate schedules in 2014.

Conclusions

The Study confirmed analysis of The EV Project in the success of incentivizing drivers to charge during off-peak times. The Study also showed that the differential price between the peak and off-peak charge times is important in driving charging behavior.

The EV Project and this Study identified that the cost associated with installing the second meter, if not subsidized by the utility or a third party, may limit enrollment in the specific TOU rates desired. The electric utility will need to determine whether the benefit derived from this change in charging behavior actually requires the addition of the second meter and justifies subsidizing the installation cost or whether the same benefit can be achieved by adjusting the whole house rate schedule.

Participants in The EV Project and this Study utilized the timing features of their Blink EVSE to allow their PEV to be connected to the EVSE at anytime, yet only charge during off-peak or super off-peak TOU periods. The convenience of this feature and the capability of the PEV to fully charge within the super off-peak period are key to supporting the charging behavior incentivized by TOU rates.

Because the existing EV-TOU-2 rate (whole house) is so similar in pricing to the EV-TOU rate, the results of this Study may be valid to apply to redesign of that rate.

The use of a smart residential EVSE, such as the Blink unit, is currently under study by the California Energy Commission (CEC) in the Sub-metering and Subtractive billing study as part of the Vehicle-Grid Integration Roadmap[7]. If the smart EVSE can meet CEC and CPUC requirements for accurately recording and reporting energy usage for billing purposes, it may negate the need for a second meter.

The EV Project and this Study illustrate that charging behavior can be modified with the proper incentive.

However, as reported in Reference 8, these changes can cause new issues in energy peaks for the electric utility. It may be possible with further work on rate design by the electric utility to incentivize charging at any time the utility desires.

About The EV Project

The EV Project was the largest PEV infrastructure demonstration project in the world, equally funded by the United States Department of Energy (DOE) through the American Recovery and Reinvestment Act and private sector partners. The EV Project deployed over 12,000 AC Level 2 charging stations for residential and commercial use, as well as over 100 dual-port DC fast chargers, in 17 U.S. regions. Approximately 8,300 Nissan LEAFs™, Chevrolet Volts, and Smart ForTwo Electric Drive vehicles were enrolled in the project.

Project participants gave written consent for EV Project researchers to collect and analyze data from their vehicles and/or charging units. Data collected from the vehicles and charging infrastructure represented almost 125 million miles of driving and 4 million charging events. The data collection phase of The EV Project ran from January 1, 2011, through December 31, 2013. Idaho National Laboratory is responsible for analyzing the data and publishing summary reports, technical papers, and lessons learned on vehicle and charging unit use.

Company Profile

Idaho National Laboratory is one of DOE's 10 multi-program national laboratories. The laboratory performs work in each of DOE's strategic goal areas: energy, national security, science, and the environment. Idaho National Laboratory is the nation's leading center for nuclear energy research and development. Day-to-day management and operation of the laboratory is the responsibility of Battelle Energy Alliance.

For more information, visit avt.inl.gov/evproject.shtml and avt.inl.gov/chargepoint.shtml.

References

[1]How do PEV owners respond to time-of-use rates while charging EV Project vehicles?, http://avt.inl.gov/pdf/EVProj/125348-714937.pev-driver.pdf

[2]"Final Evaluation for San Diego Gas & Electric's Plug-in Electric Vehicle TOU Pricing and Technology Study" Nexant, 2/20/2014, https://www.sdge.com/sites/default/files/documents/1681437983/SDGE%20EV%20%20Pricing%20%26%20Tech%20Study.pdf

[3]SDG&E Advice Letter 2157-E (U 902-E) "Establishment of Experimental Plug-In Electric Vehicle (PEV) Rates", http://www.sdge.com/rates-regulations/tariff-information/approved-electric-advice-filings

[4]EV Rates, http://www.sdge.com/clean-energy/ev-rates

[5]EV Project Quarterly Report, http://avt.inl.gov/pdf/EVProj/EVProjectInfrastructureQ22013.pdf

[6]Study, op. cit.

[7]Vehicle-Grid Integration Use Cases and Regulatory Issues, http://www.energy.ca.gov/research/notices/2014-11-19_workshop/presentations/CPUC_Vehicle-Grid_Integration_CEC_Workshop_2014-11-19.pdf

[8]"What Residential Clustering Effects have been Experienced in the San Diego Region?", http://avt.inl.gov/pdf/EVProj

Appendix A: SDG&E Study Graphics

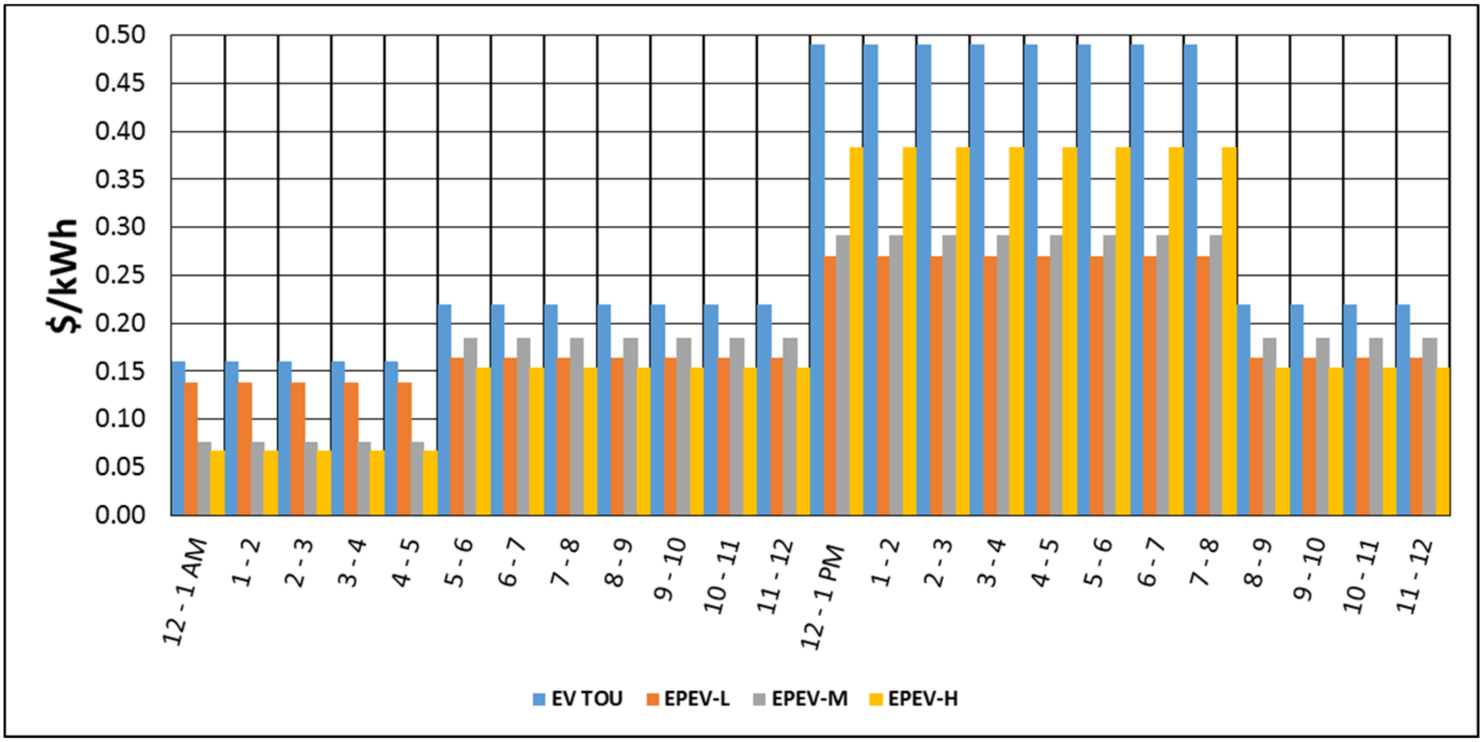

Figure A- 1. SDG&E summer rate schedules.