What Residential Clustering Effects have been Experienced in the San Diego Region?

April 2015

Key Conclusions

During a 3-month period of 2013, a review of residential charging in the San Diego region showed the following:

- The San Diego region contains several examples of residential neighbors charging plug-in electric vehicles (PEVs) simultaneously.
- Two neighbors simultaneously charging PEVs have shown a power demand nine times that of the typical San Diego residential power demand.
- Two neighbors charging their PEVs at super-off peak times can increase energy consumption by nearly five times that of those without PEVs.
- Charging PEVs at other times of the day, in addition to typical super off-peak times, can nearly double the daily energy demand by two neighbors.
- Currently, the utility impact of residential PEV charging is low because overall PEV adoption is still in its infancy. However, some transformer replacements have already been linked to cluster PEV charging.

Introduction

The EV Project enrolled over 8,000 residential participants. These participants purchased or leased a Nissan Leaf or Chevrolet Volt. The EV Project provided and installed a Blink Level 2 electric vehicle supply equipment (EVSE) used to recharge their PEV. The power required to recharge a PEV can be a significant contributor to the electrical load a residence places on the electric grid and, specifically, on the local residential power transformer providing energy to several nearby homes. What insight can EV Project data analysis provide relating to the magnitude of this impact on local transformers? A previous EV Project[1] report analyzed the San Francisco region, while this report focuses on the San Diego region.

Why is this Topic Important?

A question frequently asked relating to the adoption of PEVs is "What is the impact of PEV charging on the electrical grid?" This question can be directed at the big picture of total utility system load, but the focus here is on the impact to the local electrical distribution system and, in particular, the local residential electrical transformer. Higher than originally anticipated loads on this transformer can lead to damage, local power outages, and higher costs to the electric utility for replacement equipment.

Residential Power Distribution

Electric utility and power distribution companies work with local planners to design and deliver electrical power to residential neighborhoods. The final step in this delivery is a power feed from the local residential transformer (which may feed the residence using underground [see Figure 1] or overhead conductors) to the individual homes. Typically, more than one home is supplied by the same transformer. The transformer steps down the distribution voltage, which may range from 6 to 15 kV depending on the electric utility, to the standard North American 240-volt service. Transformer size can vary, depending on the number and size of homes served by the transformer. The number of homes served is determined by the electric utility, but could vary from one to as many as 15 homes.

Figure 1. Pad-mounted residential distribution transformer.[2]

During the design process, the anticipated residential power usage determines the capacity of the service supply and the combination of all residences served by that transformer determines its design requirements. The transformer's design also considers the peak power that will be concurrently demanded by all residences connected to the transformer and the resulting heating that will be experienced by that transformer. Because extended periods of high temperature reduce the life of the transformer, the utility design process attempts to minimize overheating of the transformer by matching its power rating to the anticipated residential demand.

When a homeowner adds a significant new load to the home (e.g., a swimming pool, hot tub, or PEV), the permitting process typically requires a new load calculation to determine whether the electric service to the home is sufficient to safely add this new load. Unless the supply is found to be insufficient, the local electric utility may not be informed of the increased load on the transformer. In most cases, the additional circuit required for EVSE does not exceed the capability of a residential electric service.

Typical Residential Loads

San Diego Gas and Electric (SDG&E) publishes the dynamic loads for residential service. Figure 2 shows a typical residential hourly load profile for June through August 2014.[3] The minimum, median, and maximum loads during this time are shown.

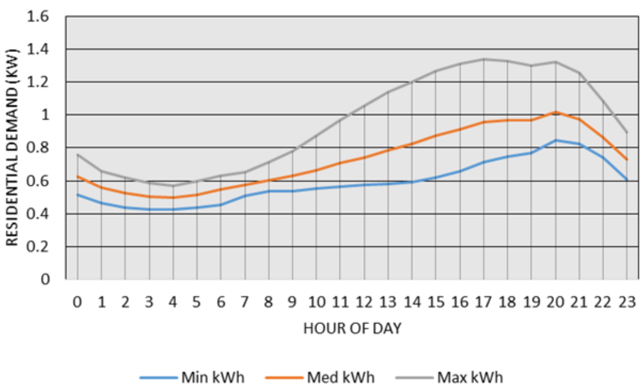

Figure 2. Dynamic residential load profile June/August 2014.

The Blink EVSE provided to EV Project participants is capable of delivering up to 7.2 kW of power to a connected PEV. While most PEVs participating in the EV Project only accepted up to 3.3 kW, model year 2013 and newer Nissan Leafs and some other vehicle models accept energy near the EVSE's 7.2-kW rating. (The Tesla Model S offers an onboard dual charger capable of charging at 20 kW.[4]) As such, it is possible that adding PEV charging to a San Diego residence could significantly increase residential demand. Where the median power demand is 1.02 kW at 8 p.m. according to Figure 2, charging the PEV at that time could raise that power demand to 8.2 kW, which is seven times the original load.

Time-of-Use Rates

Many electric utilities seek to shift peak loads to times of lower demand through time-of-use (TOU) rates. For owners of PEVs, SDG&E offers two TOU plans: EV-TOU, which requires a separate electric meter to monitor the PEV charging circuit and EV-TOU-2, which uses a single meter serving the whole house, including the charger. During the summer months (May to October), the rate charged for the energy used is determined by the time of day (shown in Figure 3).

SDG&E sets rates based on on-peak, off-peak, and super off-peak as shown in Figure 3.The price charged for power is lower for the off-peak times than for the on-peak times, incentivizing the residential customer to shift loads to off-peak times. Super off-peak further incentivizes PEV owners to program the charge of their PEV between midnight and 5 a.m. For convenience, the Blink EVSE and many PEVs provide programming capabilities to schedule the start of a charge. EV Project participant use of these programming features is the subject of a previously published report.[6] How PEV owners respond to these TOU rates is also the subject of a separate study.[7]

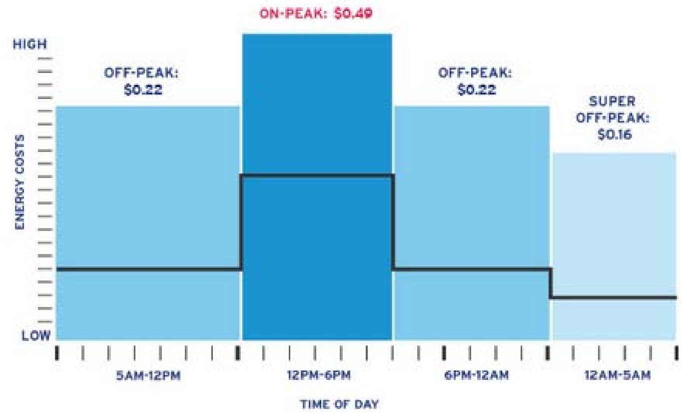

Figure 3. SDG&E residential peak schedule.[5]

The EV Project began collecting residential charging data in 2011, providing sufficient time for participating PEV drivers to settle into habits of charging. Whether San Diego PEV drivers take advantage of TOU rates or not, this residential charging data can inform electric utilities of the potential impact on the transformer.

What is Meant by "Clustering"?

Automotive manufacturers understand that one promoter of vehicle sales is the visibility of a new car in a neighbor's driveway. Neighbors are often curious and interested in the new vehicle, especially if it is a new technology vehicle such as a PEV. When several PEVs show up in the same neighborhood, where those residences are powered from the same electrical transformer, "clustering" occurs. This is a cause for concern to the local electrical utility because of the significant increase in power supplied by the transformer. While the transformer typically can accept the power demand increase from one PEV, multiple PEVs charging simultaneously may cause damage to the transformer, resulting in a service outage and the need to replace the transformer. Damage caused by overloading the transformer may occur in the short term for significant overloads or in the longer term by depriving the transformer of its normal cool-down period, typically occurring in the early morning hours.

The effects on a single transformer can also affect other residential feeders emanating from the distribution substation. Distress on a residential transformer may affect the power quality on the feeder side of the transformer.

Clustering in the EV Project

At the end of December 2013, 993 residential EVSE were installed in the San Diego region as part of the EV Project. Locations of these EVSE are shown in Figure 4.

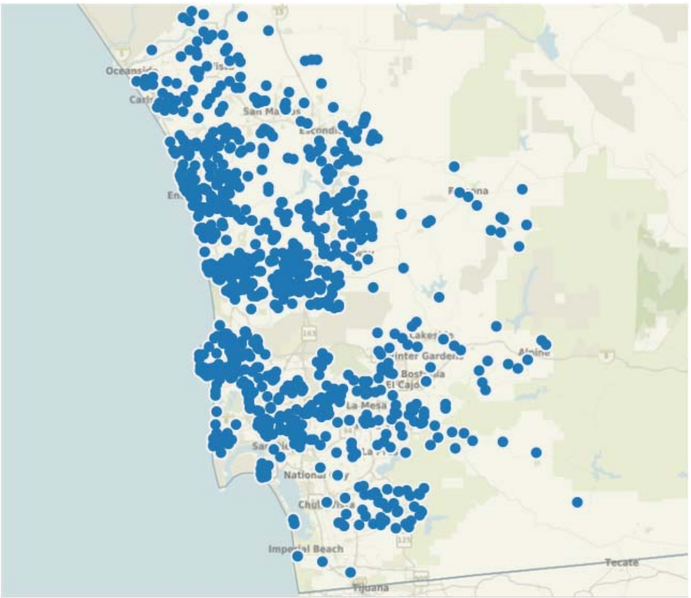

Figure 4. EV Project residential locations.

A detailed examination of these locations identified several sites where neighbors charged PEVs. Four of these sites are presented in the following sections.

Cluster Site 1

The first site for evaluation is shown in Figure 5. The street and other physical features are redacted for privacy considerations. Three residences are identified as PEV owners in The EV Project, with Houses 1 and 2 being neighbors. The third house is separated from the first two and is likely not on the same residential transformer. A review of the Blink charge data indicate that a Chevrolet Volt is charged in one home and a Nissan Leaf in the other. In both homes, the start of the evening charge is programmed, but one starts at midnight and the other at 1 a.m.; however, additional charge times might occur during the day.

Staggering of charge times has been seen in many EV Project sites as PEV owners, whether intentionally or unintentionally, attempt to either reduce peak loads or desire to ensure their start time occurs fully within the super off-peak time.

Both homes charge near the 3.3-kW rating. The PEV charging profile for these residences for a few days in August 2013 is shown in Figure 6.

Figure 5. Cluster Site 1 Location.[8]

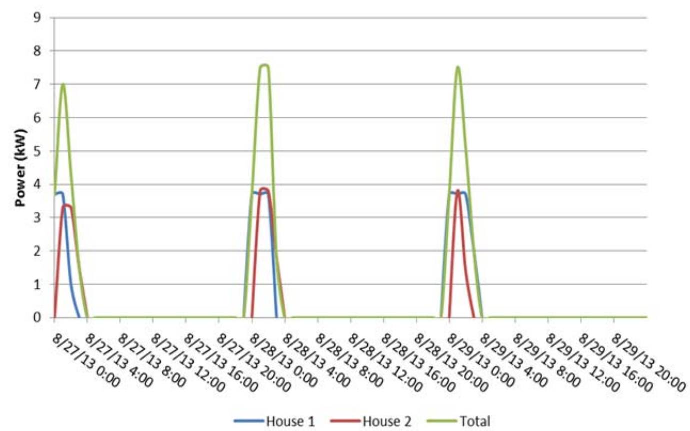

Figure 6. PEV charging profile for Cluster Site 1.

Even though the charge start times are staggered, a peak at twice the power of a single unit is seen because both are charging at 1 a.m. Assuming the median load profile of Figure 2 for both houses, the cumulative load profile for these two houses at this time would be as shown in Figure 7.

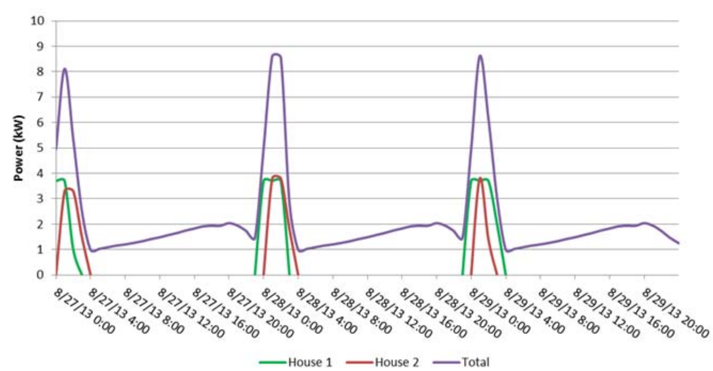

Figure 7. Hourly load profile for Cluster Site 1.

Energy used by the houses from midnight to 3 a.m. without considering PEVs is 3.4 kWh. With the PEVs added, the energy for the same period is 18.4 kWh, which is over a four-fold increase. As shown in Figure 7, this increase also occurs during the typical period of expected transformer cool down.

Charging usage superimposed on the typical residential load profile of Figure 2 is shown in Figure 8. The effects of using minimum, median, or maximum load curves are lost in the magnitude of this increase.

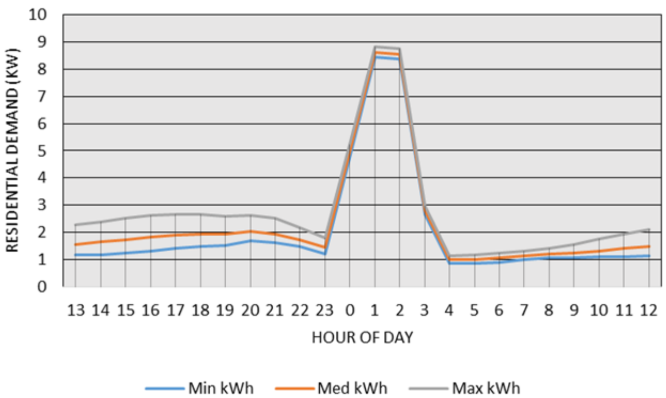

Figure 8. SDGE load profile with Cluster Site 1.

Cluster Site 2

Cluster Site 2, with Nissan Leafs at two neighboring homes, is shown in Figure 9. Charging of these Leafs is similar to Cluster Site 1 in that the home owners stagger their start times in the super off-peak times. This site was selected to illustrate the effects of additional daytime charging.

Figure 9. Cluster Site 2 location.

Both homes charge at approximately 3.3 kW. The charge profile, including the median household demand, is shown in Figure 10.

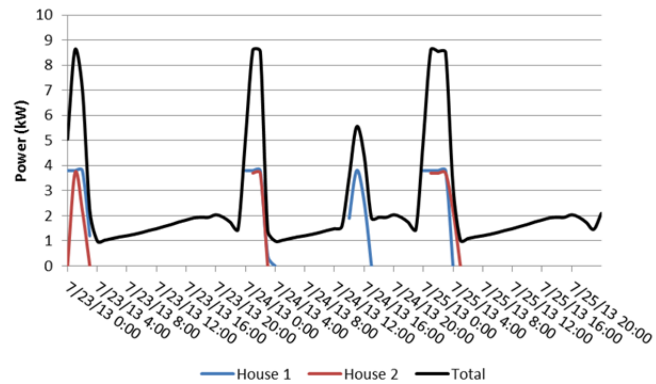

Figure 10. Hourly load profile for Cluster Site 2.

Without PEV charging, the total energy delivered to the neighbors on July 24, 2013, would have been 35.1 kWh. With PEV charging, it was 62.6 kWh, nearly double the energy. Because this charging behavior depends on the PEV owners' use of their PEVs, this increased load on the transformer could occur at any time, including both neighbors charging at night and during the day.

Cluster Site 3

The next site for evaluation is shown in Figure 11. A review of the Blink charge data indicates that in both homes, the start of the evening charge is programmed at midnight (i.e., at the beginning of the SDG&E super off-peak period), although additional charge times might occur during the day.

Figure 11. Cluster Site 3 location.[7]

Data indicate one residence charging a Leaf at 6.6 kW, while the other charges a Volt at 3.3 kW. The PEV charging profile for these residences, including the median load profile, for a few days in July 2013 is shown in Figure 12. The peak power demand is 11.2 kW. This is nine times the peak of the household power alone.

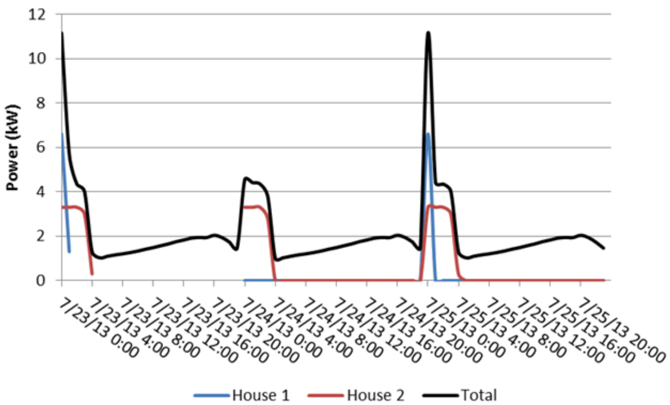

Figure 12. PEV charging profile for Cluster Site 3.

Energy used by the houses from midnight to 4 a.m. without charging PEVs is 4.4 kWh. With the PEVs added, the energy for the same period is 25.2 kWh, which is over five times the non-PEV energy. Again, this increase also occurs during the typical period of expected transformer cool down.

Cluster Site 4

The final site for evaluation is shown in Figure 13. Data from all three houses show typical programmed start times of midnight daily for Leaf vehicles, although some days were missed and some charging occurred at other times as well.

Figure 13. Cluster Site 4 location.

The charging profile for the PEVs located in these homes for a few days in July 2013 is shown in Figure 14.

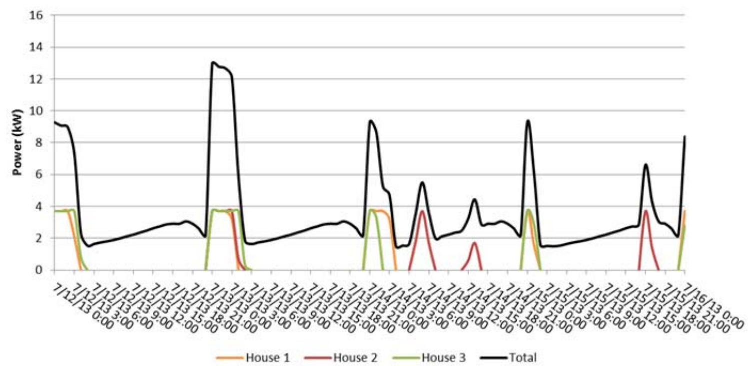

Figure 14. PEV charging profile for Cluster Site 4.

The Blink charge data for all three vehicles show a maximum charging power of 3.7 kW each.

This cluster illustrates the varied nature of individual charging. There were times that all three PEVs were recharging, times that two were charging simultaneously, and times of isolated charging during peak times.

As expected, the effects of three households in the cluster magnify the impacts on the transformer. The total energy increase through the transformer for the 4 days of July was 132 kWh, which is an increase of 62%. The higher peak power demand (i.e., 13 kW) compared to the normal three households at midnight (i.e., 1.9kW) and lack of cool down periods due to coincident and non-coincident charge events, significantly changes the operation of the neighborhood transformer.

Higher Power Charging

Cluster Site 3 included a PEV capable of 6.6-kW charging. If the three home owners in Cluster Site 4 also had vehicles of 6.6-kW charge capability, the use of each vehicle was the same, and the same charging energy was required, the new combined household load would be as shown in Figure 15.

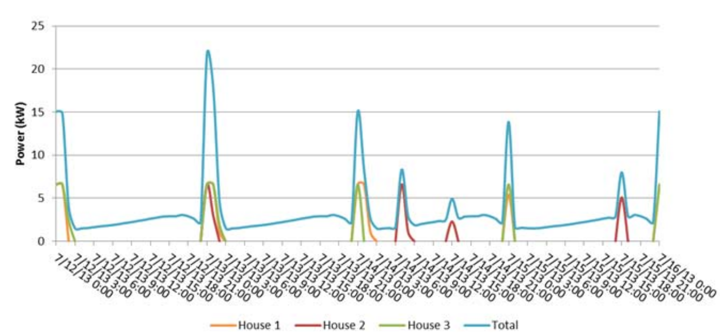

Figure 15. Hourly load profile for Cluster Site 3 with 6.6-kW charging.

This creates vastly higher peaks of shorter duration. The same energy requirement exists as in Cluster Site 3, but the peak power demand of 21.6 kW is 11.5 times the typical three residential households demand and remains at high power for at least 2 hours.

Utility Experience

The mild climate of San Diego leads to relatively small typical household loads, allowing smaller capacity neighborhood transformers or many houses being fed by the same transformer. While the transformer may be large relative to an individual house load (and thus, able to withstand the transient charging loads from a single PEV), the many households served creates the potential for much larger clusters as PEV adoption grows.

SDG&E is informed of residential EVSE installations during the permitting process. At this writing, the utility has, in fact, replaced a few transformers linked to cluster effects. While SDG&E is monitoring and testing some neighborhood transformers where PEV charging occurs, the low impact experienced thus far from the relatively small population of PEV owners has led to a reactive strategy (i.e. replacing the transformer should a problem arise). Special situations (e.g., when Tesla home charging occurs) require proactive analysis of the local transformer. However, utilities are actively monitoring the growth of PEV adoption, understanding that it can have major effects on their power distribution.

Conclusions

These EV Project data demonstrate the loads observed on residential transformers and confirm clustering of PEV charging has occurred among EV Project participants. At this writing, the adoption of PEVs is still in its infancy, with more PEVs sold beyond those sold to the participants within the project regions, increasing the possibility of clustering in many areas. The effects of clustering on neighborhood transformers using EV Project charging data include higher peaks, longer operation at higher power, and periods of high power demand during times when residential transformers are traditionally expected to have only low loads. The true impact of these loads varies greatly from utility to utility, depending on factors such as the age of the transformers used in each territory and the design considerations that were in place at the time they were installed.

These effects may be heightened by factors such as TOU electricity rates that influence PEV drivers to choose common charging times. The electric utility rate structures for TOUs can contribute to the impact on the local transformer by creating a new peak in demand at the beginning of the off-peak period.

The PEV market is growing. As adopters demand greater vehicle range and shorter charge times, the vehicle battery capacity is likely to increase, along with the capability for higher charging power. Doubling the recharge power from 3.3 to 6.6 kW has already occurred, with a multiplying effect on residential distribution transformer impacts.

Clustering effects may result in service outages and the need to upgrade transformers. Damage to the transformer may be caused by exceeding the transformer's load rating or by depriving it of its normal cool-down period. Electric utilities will need to be involved with PEV adoption, both for the overall system load profile and for impacts to the local neighborhood distribution transformer. Understanding the likelihood and effects of clustering will help electric utilities prepare for widespread PEV adoption.

About The EV Project

The EV Project was the largest PEV infrastructure demonstration project in the world, equally funded by the U.S. Department of Energy (DOE) through the American Recovery and Reinvestment Act and private sector partners. The EV Project deployed over 12,000 alternating current Level 2 charging stations for residential and commercial use and over 100 dual-port direct current 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]"What Clustering Effects have been Seen by the EV Project," August 2013, http://avt.inl.gov/pdf/EVProj/126876-663065.clustering.pdf, accessed January 9, 2015.

[2]Distribution Systems: Distribution Transformers Occupational Safety & Health Administration, https://www.osha.gov/SLTC/etools/electric_power/illustrated_glossary/distribution_system/distribution_transformers.html, accessed July 30, 2013.

[3]http://www.sdge.com/customer-choice/customer-choice/dynamic-load-profiles, accessed January 9, 2015.

[4]http://www.teslamotors.com/charging/#/basics accessed February 4, 2015.

[5]http://www.sdge.com/clean-energy/ev-rates, accessed January 19, 2015.

[6]"EVSE Programming," April 2013, http://avt.inl.gov/evproject.shtml#LessonsLearned, accessed January 19, 2015.

[7]"PEV Driver Response to Time-of-Use Rates while charging EV Project vehicles," July 2013, http://avt.inl.gov/evproject.shtml#LessonsLearned, accessed January 19, 2015.

[8]Residential pictures provided by Google Earth.