What Clustering Effects have been Seen by The EV Project? August, 2013

The EV Project has 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) battery, was installed at their residences. The power required to recharge a PEV can be a significant electrical load for the house on the electric grid and, specifically, on the local residential power transformer providing energy to several homes. What insight can The EV Project data analysis provide relating to the magnitude of this impact on the local transformer?

Why is this 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 could 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 the residential neighborhoods. The final step in this delivery is from the local residential transformer to the individual homes. Frequently, more than one home is supplied by the same transformer, as illustrated in Figure 1. Here, the transformer (shown in beige in Figure 1 and also shown in Figure 2) provides the electrical energy to the individual residential service entrance. The supplied voltage is typically 240 volts AC, from which the residence can power its 240- and 120-volt loads.

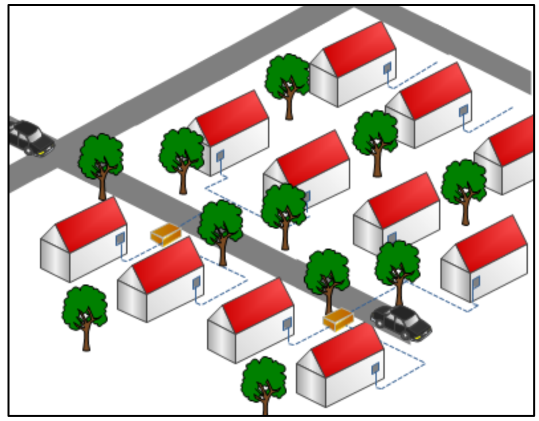

Figure 1. Residential Distribution Transformer Schematic

In 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. Appropriate standards and regulations apply in providing safety and operational margins in these calculations. The transformer design also considers the peak power that will be demanded by all the residences at one time and the heating effects that will be experienced on that transformer. An assumption is made for the amount of time available to allow the transformer to cool down between these peak loads.

Figure 2. Pad-mounted Residential Distribution Transformer[1]

When a homeowner desires to add significant load in his or her home (such as adding a swimming pool, welder, or PEV), the permitting process typically requires new load calculations to determine whether the residences service supply 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 new load on the transformer. In many cases, the addition of the EVSE for charging the PEV may not exceed the service supply design of the single residence, so the electric utility may not know of the change.

Typical Residential Loads

A typical residence in the Pacific Gas & Electric (PG&E) service territory may reach a maximum electrical power demand of approximately 2.5 kW during a given year. Figure 3 shows a typical residential hourly load profile for 2012[2]. The E-7 profile includes the PG&E residential time-of-use (TOU) Schedule E-6 rates and experimental EV TOU Schedule E-9 rates. (Note: the source files show an apparent error for the 3 AM time period of a zero value on March 3, 2012.)

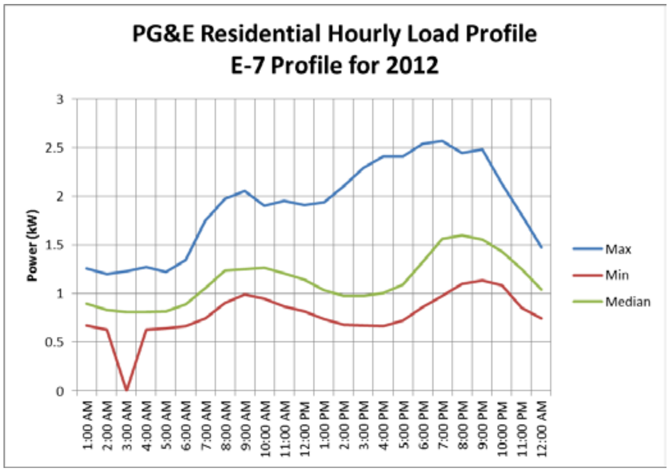

Figure 3. PG&E Hourly Residential Load Profile

The Blink EVSE provided to The EV Project participants is capable of delivering up to 7.2 kW power to a connected PEV. While most PEVs currently on the market accept up to 3.6 kW, model year 2013 Nissan Leafs and other vehicle models will accept energy near the EVSE's 7.2 kW rating. As such, it is possible that adding PEV charging could significantly increase the residential demand. Where the median power demand is 1.5 kW at 7 PM according to Figure 3, charging the PEV at that time could raise that power demand to 8.7 kW - nearly 6 times the original load. If the PEV charging occurs at the time of greatest demand, the total residential demand could reach 9.7 kW.

TOU rates

Some electric utilities seek to shift peak loads to times of lower demand through time-of-use (TOU) rates. These rates generally classify times of the day as "On-Peak" and "Off-Peak", and in some cases, a "Shoulder", "Partial-Peak" or "Mid-Peak".

Pacific Gas and Electric (PG&E) defines summer weekday times on Electric Schedule E-9 as:

On-Peak: 2- 9 PM
Partial-Peak: 7 AM – 2 PM and 9 PM – 12 AM
Off-Peak: All other times[3]

The price charged for power is typically lower for the off-peak times than for the on-peak times, in order to incentivize the residential customer to shift loads to off-peak times. While it may not be possible to shift all loads (such as air conditioning), it is possible to shift power to operate swimming pool pumps, clothes dryers, and so on, to these off-peak times. The same is true for PEV charging. For convenience, the Blink EVSE and many PEVs provide programming capabilities to schedule the start of a charge. Many EV Project participants use these tools to schedule the start of charge after the start of the utility off-peak time. EV Project participant use of these programming features is the subject of another report[4]. How PEV owners respond to these TOU rates is the subject of a separate study[5].

The EV Project has been collecting residential charging data since 2011, which is long enough for the participating PEV drivers to settle into habits of charging, regardless of motivations. Whether these 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 type of vehicle, such as a PEV. When several PEVs show up in the same neighborhood and where those residences are powered from the same electrical transformer, "clustering" occurs. This is a cause for concern to the local electrical utility. While the transformer may be able to accept the power demand increase from one PEV, multiple PEVs charging may cause damage to the transformer, resulting in a service outage and the need to upgrade that transformer. This damage may be caused by overloading the rating of the transformer or by depriving the transformer of its normal cool-down period, typically found in the early morning hours.

The effects on a single transformer can also affect the rest of the residential feeders from the distribution substation. Distress on a residential transformer may affect the power quality on the feeder side of the transformer. Distribution feeders are generally designed either in a radial pattern away from the substation or in an interconnected method where multiple connections may be made to other feeders[6]. In the former radial design, the closer this clustered transformer is to that substation, the greater the effects on those residential transformers farther away because the power quality is diminished.

Clustering in The EV Project

Typically, residences are located within 100 feet of the local neighborhood transformer. To see whether there might be cases of clustering in The EV Project, the locations of The EV Project participants in the San Francisco region were plotted. 100-foot radius circles or "buffers" were drawn around each location. Areas where these buffers intersect are locations where the homes may be serviced by the same neighborhood transformer.

Figure 4 shows a section of the San Francisco Bay Area where two or more of these 100-foot buffers intersect. Note that not all EV Project participant locations in this part of the Bay area are shown; only those where there are intersecting buffers are shown. There are 21 such locations shown in this section of the Bay Area alone.

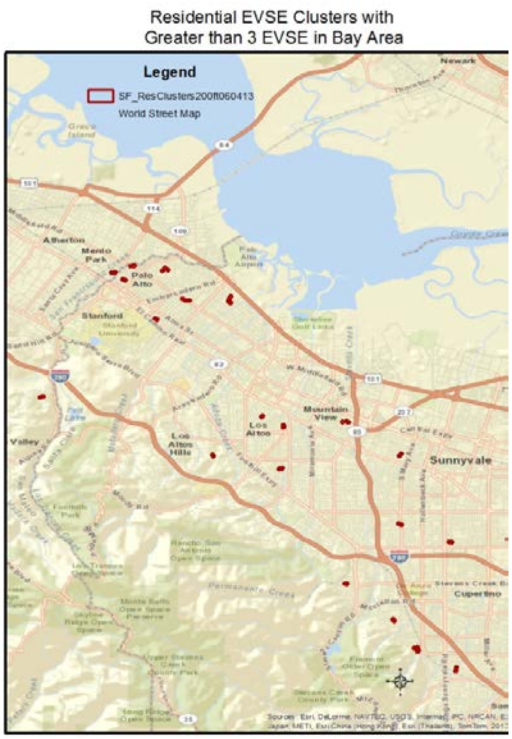

Figure 4. Residential EVSE Clusters in the Bay Area

Three sites of 2 or more intersecting buffers in the Bay Area were selected for evaluation.

Cluster Site 1

The first site for evaluation is shown in Figure 5. The street and other physical features are redacted for privacy considerations. The two residences shown with 100-foot buffer zones are, in fact, neighbors. The homes are located within the PG&E service territory. A review of the Blink charge data indicates that in both homes, the start of the evening charge is programmed after midnight (after the beginning of the PG&E off-peak period), although additional charge times might occur during the day.

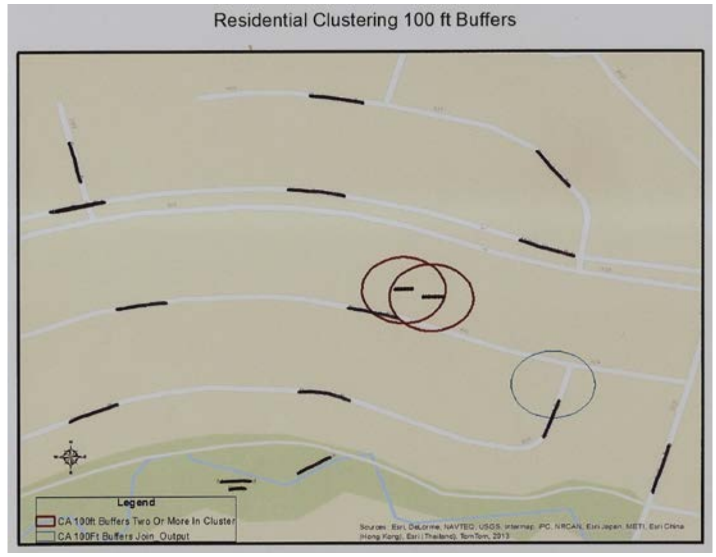

Figure 5. Cluster Site 1 Location

The PEV charging profile for these residences for the first few days of April 2013 is shown in Figure 6.

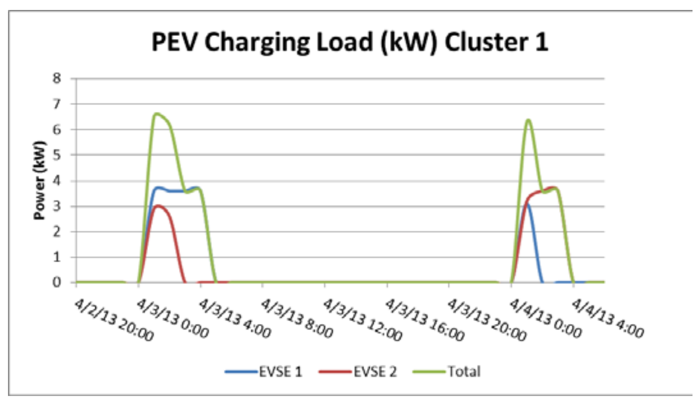

Figure 6. PEV Charging Profile for Cluster Site 1

The Blink charge data show that both PEVs are capable of accepting up to 3.6 kW power. Assuming the median load profile of Figure 3 for both houses, the cumulative load profile for these two houses for April 2-4, 2013 would be as shown in Figure 7.

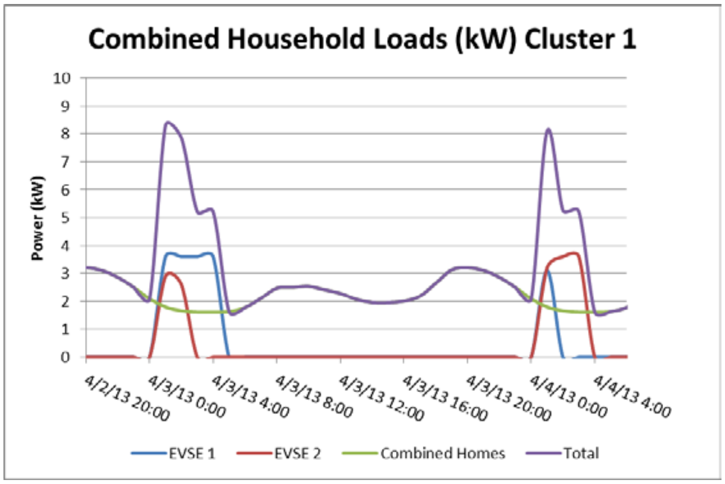

Figure 7. Hourly Load Profile for Cluster Site 1 4/2/13 - 4/4/13

Charging the PEVs requires the neighborhood transformer to provide almost four times the amount of energy through 4 AM than would be provided for the houses without charging taking place.

Cluster Site 2

The second site for evaluation is shown in Figure 8. The two residences are shown with intersecting 100-foot buffer zones. The homes are located within the PG&E service territory. According to the Blink charge data, the charge for the PEV in House 1 is programmed to start during the off-peak time at 1 AM. For the month of June, charging was conducted at no other time of day at this house. The charge for PEV in House 2 is also programmed to start during the off-peak time at midnight, although this program has been over-ridden with additional charge times when connecting at night or during the day.

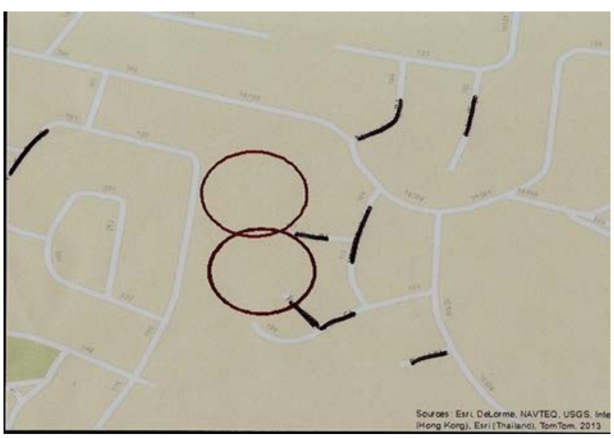

Figure 8. Cluster Site 2 Location

The PEV charging profile for the PEVs located in these homes for first few days of June 2013 is shown in Figure 9.

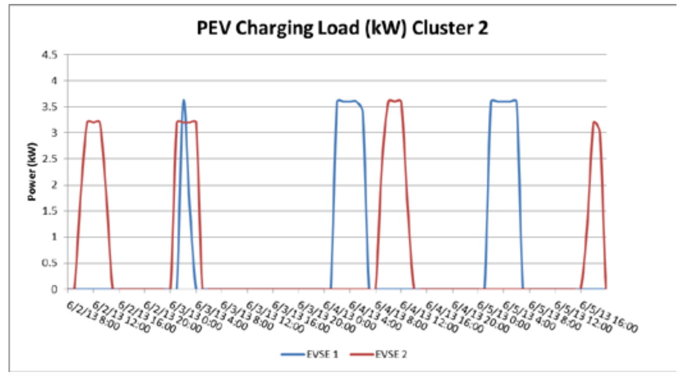

Figure 9. PEV Charging Profile for Cluster Site 2

As before, the charge data show both vehicles can accept up to 3.6 kW charge power. Assuming the median load profile of Figure 3 for both houses, the cumulative load profile for these two houses for June 2-5, 2013 would be as shown in Figure 10.

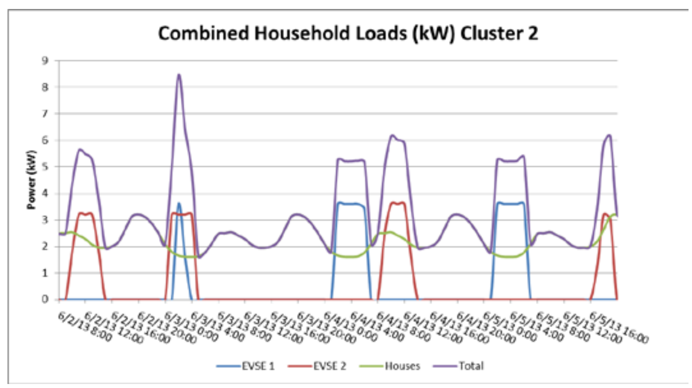

Figure 10. Hourly Load Profile for Cluster Site 2 6/2/13 – 6/5/13

The PEV charging in these two homes shows three separate effects on the local transformer. First, the peak caused by simultaneous charging is shown for the early morning hours on June 3. Next, the early morning of June 4 shows the sequential charging peaks during the time when electric utilities anticipate lowest residential demand. Thus, the anticipated overnight cool-down time for the transformer is eliminated. Finally, other morning charging in House 2, as shown on June 2 and June 5, adds peaks in the daytime that also can affect transformer cool-down during other typically lower demand times.

Cluster Site 3

The third site for evaluation is shown in Figure 11. The three houses in the intersecting circles are neighboring houses on the same street. All are located in PG&E service territory. The charging of the PEV in House 1 showed regular programmed start times of 12:05 AM daily, but also frequent charging at other times. The charging of the PEV in House 2 showed regular programmed start times of 12:10 AM daily and had some charges at other times. The charging of the PEV in House 3 did not appear to be based upon a schedule, but commenced at PEV plug-in.

Figure 11. Cluster Site 3 Location

The charging profile for the PEVs located in these homes for first few days of June 2013 is shown in Figure 12.

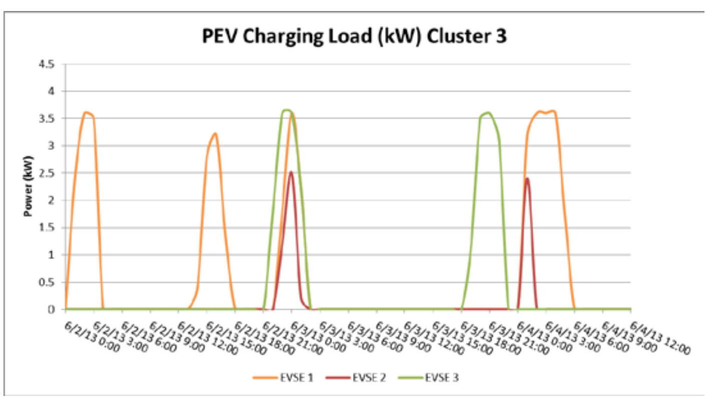

Figure 12. PEV Charging Profile for Cluster Site 3

The Blink charge data for all three vehicles show a maximum charge acceptance of 3.6 kW each. It is noted that during the above days, the PEV in House 2 accepted less than 3.6 kWh because of lower recharge needs on these days. Later charging was observed at the 3.6 kW rate.

In this cluster, there are times that all three PEVs are recharging, and times that two are charging simultaneously, followed by the third. Other non-coincident charges also occur. Assuming the median load profile of Figure 3 for all houses, the cumulative load profile for these three houses for June 2-4, 2013 would be as shown in Figure 13.

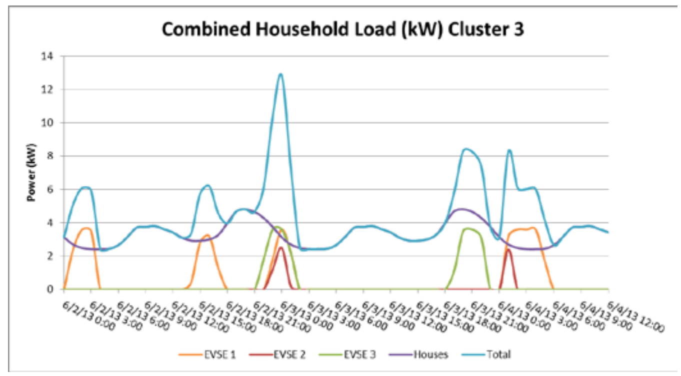

Figure 13. Hourly Load Profile for Cluster Site 3 6/2/13 – 6/4/13

As expected, the effects of three households in the cluster magnify the impact on the transformer. The total energy increase through the transformer for the 3 days of June was 69.3 kWh - an increase of 28%. The impacts of higher peak power demand (4 times normal) and lack of cool down periods due to coincident and non-coincident charge events, could be stressing the neighborhood transformer.

Higher Power Charging

Suppose the three home owners in Cluster Site 3 trade in their current Leafs for newer models that have 7.2 kW charge capability. Assuming that the use of each vehicle is the same, and the same charging energy is required, the new combined household load would be as shown in Figure 14.

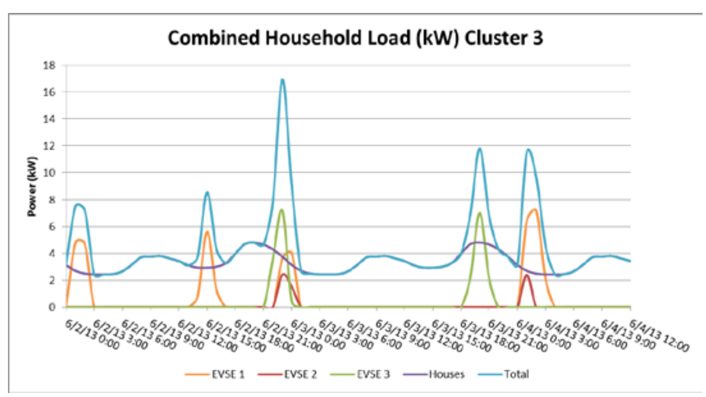

Figure 14. Hourly Load Profile for Cluster Site 3 w/ 7.2 kW Charging

This creates vastly higher peaks of shorter duration.

Observations

All of these household load curves assumed the median value for household energy usage. Usage below this median value would reduce the impact slightly, but PEV drivers would still need to charge their vehicles on the days when the whole-house demand is at its peak. This further exacerbates the impact on the transformer. These EV Project data demonstrate the possible loads on residential transformers. The true impact of these loads varies greatly from utility to utility depending on such factors as the age of the transformers used in each territory and the design considerations that were in place at the time they were installed (in terms of their ability to handle additional loads).

Mitigating Suggestions

It has been suggested that smart charging of the EVSE at night can mitigate these peaks and lessen the impact on the local transformer. Smart charging includes methods by which the electric utility can communicate and control the household smart EVSE by various means. Assuming that the PEV driver simply requires that his or her battery is charged when the PEV is needed at a certain time of day regardless of when the charge starts and stops, the utility could determine at what time and what power the energy is delivered to the connected vehicles. The utility would then signal the smart EVSE to deliver the desired power and energy.

Assuming all three residences participate in such a program, Figure 15 shows a scenario by which the same energy is delivered to the three PEVs in their overnight charging. It is assumed that an engaged PEV driver would defer most charging, if possible, to the evening controlled hours. For example, House 3 could move the evening charge of June 3, 2013 to midnight. However, House 1 charge data suggests that the mid-afternoon charge on June 2, 2013 was required because the PEV was driven again after this charge. In this scenario, all controlled PEV overnight charging commences after midnight and is completed before 5 AM.

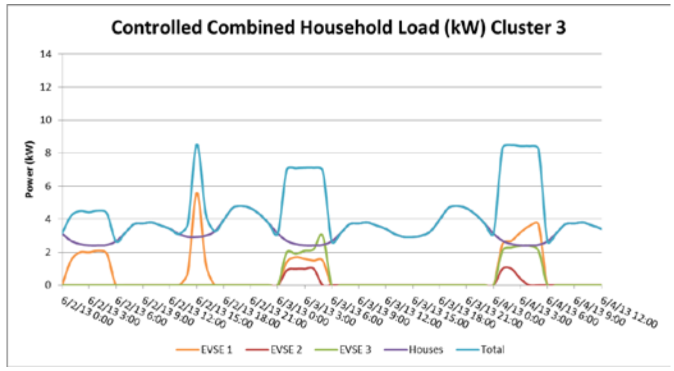

Figure 15. Controlled Hourly Profile for Cluster Site 3 w/ 7.2 kW Charging

The maximum peak power reached is 8.5 kW at 2 PM as opposed to the 17 kW actual demand at 11 PM shown in Figure 12. Because this peak occurs at a typically lower residential demand due to theoretical load control, it is only 3.4 times the normal transformer peak for these homes, as opposed to 4.5 times that peak. Further reduction in the peaks could occur if the PG&E off-peak window were increased to start at 10 PM, or if the PEV driver did not need the PEV until 6 AM. A smart system could consider these personal preferences and utility rate structures.

Conclusions

The EV Project has indeed observed clustering among the project participants. More PEVs have been sold beyond those sold to the participants within the project regions, increasing the possibility of clustering in many areas. The effects of clustering on the 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. 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 TOU might be contributing to the impact to the local transformer by creating a new peak in demand at the beginning of the off-peak period.

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 is the largest electric vehicle infrastructure demonstration project in the world; designed and managed by ECOtality North America (ECOtality), with a budget of over $230 million USD, equally funded by the United States (U.S.) Department of Energy (DOE) through the American Recovery and Reinvestment Act and ECOtality and its partners. The EV Project will deploy and study approximately 13,000 AC Level 2 EVSE charging stations for residential and commercial use, as well as 200 dual-port DC Fast Chargers in conjunction with the usage data from 8,000 Nissan LEAF™ and Chevrolet Volts. This project will collect and analyze data, and publish lessons learned on vehicle and EVSE use, and driver behavior. This material is based upon work supported by the DOE under Award Number DE-E0002194.

Company Profile

ECOtality, Inc. (NASDAQ: ECTY), headquartered in San Francisco, California, is a leader in clean electric transportation and storage technologies. Its subsidiary, Electric Transportation Engineering Corporation (eTec) dba ECOtality North America (ECOtality), is a leading installer and provider of charging infrastructure for PEVs. ECOtality has been involved in PEV initiatives since 1989 in North America and is currently working with major automotive manufacturers, utilities, the U.S. DOE, state and municipal governments, and international research institutes to implement and expand the presence of this technology for a greener future.

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For more information, visit www.theevproject.com

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