A Comparison of Electric Vehicle Level 1 and Level 2 Charging Efficiency

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***Abstract*— As electric vehicle penetration grows, it is important to ensure that this new technology is deployed such that long-term efficiency and environmental benefits are maximized. In this study we examined the charging efficiency of Level 1 (120 Volt) and Level 2 (240 Volt) Electric Vehicle Supply Equipment (EVSE). Charging efficiency was defined as the percentage of power drawn from the electric grid that is actually taken up by the vehicle battery.**

We installed logging devices in 2 Nissan Leafs and 2 Chevrolet Volts in Vermont to track charging efficiency at each Level 1 and Level 2 charging event. Data was collected between June and November 2013 to provide a range of climatic conditions. Usable data was obtained from 115 charges and mean charging efficiency was found to be 85.7%. On average, Level 2 charging was 5.6% more efficient than Level 1 (89.4% vs. 83.8%). In those charges in which the battery took up less than 4 kWh, this difference in efficiency was even greater: 87.2% for Level 2 vs. 74.2% for Level 1. Efficiency gains of Level 2 charging also increased under low (< 50°F) and high (> 70°F) temperatures. These results suggest that the impact of the observed efficiency gains may be biggest at public charging stations, where charging times tend to be short and climatic conditions more variable, rather than residential charging.

Future research should consider the relative efficiency of DC Fast charging and wireless charging, as well as how charging efficiency varies among vehicle models and at lower temperatures (<32°F).

Keywords*— *electric vehicles; charging efficiency, electric vehicle supply equipment

I. INTRODUCTION

As penetration of electric vehicles (EVs) rapidly increases, it is crucial that this transformative technology be deployed such that long term efficiency and environmental benefits are maximized. Over 150,000 plug-in vehicles have been sold in the US since 2012 and this number is expected to continue to grow rapidly as these vehicles become more widely available [1]. Because EVs present a sizable new source of potential demand for electricity, charging needs to be managed optimally, for instance through Time Of Use rates that encourage plugging in off-peak and randomized smart charging techniques that flatten demand profiles [citation- IEEE paper- Hilshey?].

Another area where efficiency gains can be made is through charging equipment. Previous work has suggested that Level 2 EVSE may be more efficient than Level 1, that is, that a greater proportion of the energy drawn from the grid is actually taken up by the battery when Level 2 charging is used [2]. Research on the Chevrolet Volt found Level 2 EV charging to be 2.7% more efficient than Level 1 charging, on average, and as much as 12.8% more efficient for shorter charge events that draw less than 2kWh from the grid.

If Level 2 charging infrastructure is found to offer consistent efficiency gains over Level 1, this equipment may be eligible for incentives under electric utility efficiency programs, similar to other electric appliances. Utility efficiency programs in Washington and Vermont have already been asked to consider incentivizing Level 2 EVSE. Such programs could contribute to increased penetration of EVs in the vehicle fleet and a more rapid transition to an electrified transportation sector.

We continued this line of research into Level 1 and Level 2 charging efficiency with a field study in Vermont. The objectives of this study were to:

(1) determine the difference, if any, in overall charging efficiency of Level 1 and Level 2 EVSE;
(2) determine how charge duration affects charging efficiency of Level 1 and Level 2 EVSE;
(3) determine how ambient temperature affects Level 1 and Level 2 charging efficiency.

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II. METHODS

We recruited four volunteer EV owners to participate in our study: two Chevrolet Volt drivers (a plug-in hybrid electric vehicle) and two Nissan Leaf drivers (an all-electric vehicle). We installed logging devices in these vehicles to measure charging efficiency of each vehicle charging event. Although our sample size was limited, the study is intended to provide preliminary data and results on this topic. All vehicles were located and charged in Vermont, USA, and data was collected between June and November 2013. The Volts were outfitted with the C-5 logging device from the company FleetCarma. These loggers plugged into the vehicle dash and collected data on the amount of energy received from the EVSE and the amount taken up by the vehicle battery.

There was no similar device available for the Nissan Leaf (one that directly measures energy uptake by both the vehicle charger and the vehicle battery) but we wanted to ensure that at least two EV models were included in our study. To estimate charging efficiency of the Nissan Leaf, a vehicle logging device was used in combination with a meter on the EVSE unit. One device, the WattsLeft™ monitor was plugged into the vehicle and measured the amount of energy taken up by the battery at each charging event. Another device, the Watts Up meter, was attached to the EVSE unit and measured the amount of energy that was taken from the grid during each charging event.

Because previous research indicated that charging efficiency of the Chevrolet Volt was affected by ambient temperature and charge duration [2], we also examined the effects of these factors on charging efficiency. Hourly temperature data for each charge event was obtained from the Cornell Northeast Regional Climate Center.

For both logging devices, the efficiency of each charge event was calculated as:

$$\textit{(total energy taken up by the vehicle battery)} \div \textit{(total energy drawn from the grid)} \times 100 \quad (1)$$

III. RESULTS

Usable data was collected from a total of 115 charge events, 64 Level 1 and 51 Level 2. Of these charge events, 75 were Chevrolet Volts and 39 were Nissan Leafs. We found mean charge efficiency for all charge events to be 85.7% ± 0.09 SD (Table 1).

Level 2 charges were consistently more efficient than Level 1, by 5.6% on average. We also observed that the efficiency of charge events in which the vehicle battery took up less than 4 kWh, was generally lower,

TABLE I. LEVEL 1 AND 2 EV CHARGING EFFICIENCY

	N	*Mean Charge Efficiency (%) ± SD*
All charge events	114	85.7 ± 0.09
All Level 1 charge events	63	83.8 ± 0.08
All Level 2 charge events	51	89.4 ± 0.05
Level 1 charge events < 4kWh	11	74.2 ± 0.12
Level 2 charge events < 4kWh	13	87.2 ± 0.06
Level 1 charge events < 50°F	32	83.0 ± 0.09
Level 2 charge events < 50°F	9	90.6 ± 0.04
Level 1 charge events >70°F	23	81.4 ±0.09
Level 2 charge events >70°F	10	89.9 ± 0.04

especially for Level 1 charging (Figure 1, Table 2). Level 1 charge events < 4kWh exhibited an average charge efficiency of 74.2% and Level 2 charge events < 4kWh exhibited a mean efficiency of 87.2%.

We obtained charging data from a wide range of temperatures over the course of the study period: 25°F to 88°F. Mean observed temperature was 54°F. For 41 charge events, the average temperature over the course of the charge was less than 50° F. For 33 charge events, the average temperature was greater than 70°F.

We observed that high ambient temperatures (> 70°F) reduced charging efficiency of Level 1 charges to 81.4%, but there was no similar effect observed for cold temperatures (< 50° F). Ambient temperature did not appear to affect the efficiency of Level 2 charge events within the temperature ranges examined (Figure 2). There may be effects on charging efficiency at lower temperatures (e.g., < 40°F or < 30°F) but we did not have enough observations for both Level 1 and Level 2 charging events at these temperatures to assess these effects.

TABLE II. EFFICIENCY GAIN OF LEVEL 2 EVSE CHARGING RELATIVE TO LEVEL 1

	N	*Efficiency gain of Level 2 over Level 1*
All charge events	114	5.6 %
Charge events < 4kWh	24	13%
Charge events < 50°F	41	7.6%
Charge events >70°F	32	8.5%

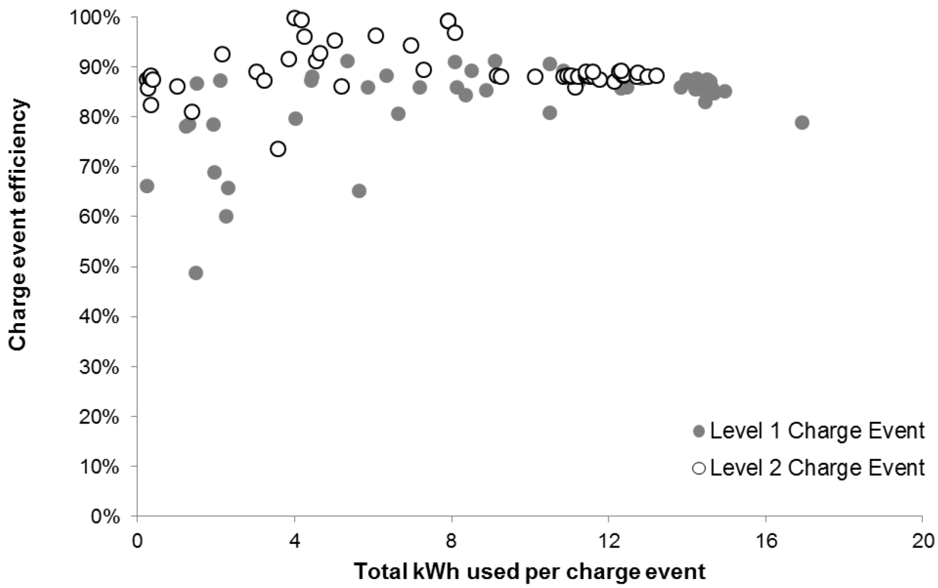

Figure 1. Charge event efficiency vs. total kWh use per charge for Level 1 charge events (n= 63) and Level 2 charge events (n= 51).

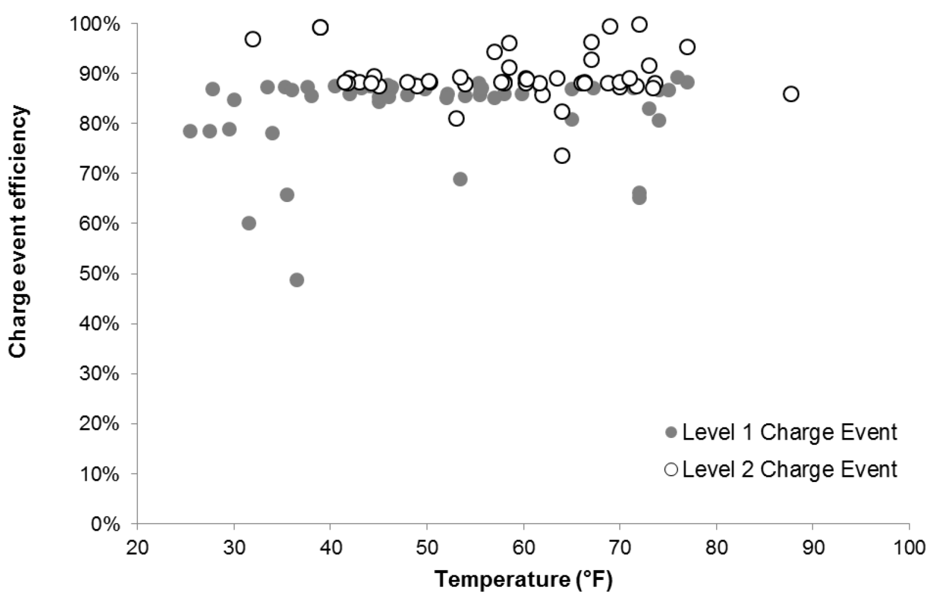

Figure 2. Charge event efficiency vs. ambient temperature (°F) for Level 1 charge events (n= 63) and Level 2 charge events (n= 51).

IV. Discussion

The efficiency gains of EVs over conventional internal combustion engine vehicles are well documented [source]. By most estimates, EVs are up to three times more efficient than conventional gasoline vehicles. In this research we explore an additional source of efficiency: EV charging equipment.

Our results confirm earlier research showing efficiency gains from Level 2 EV charging over Level 1 charging. Further, we also confirmed earlier results that showed the efficiency gains of Level 2 charging are more pronounced in charge events where the vehicle battery took up less than 4 kWh. For Level 1, these low energy charge events will have a maximum duration of approximately 1.5 to 3 hours, depending on the size of the charger inside the vehicle. For Level 2, the maximum duration of these events is approximately 1 hour or less [5]. Because charge duration at public EVSE is generally shorter than home EVSE, this research suggests that Level 2 EVSE may be ideal for public charging stations, not only to maximize EV range and potential e-miles, but to maximize efficiency of the energy delivered.

Data from public charging stations in retail and downtown locations in Vermont reveal mean charge durations ranging from 45 minutes to 1:40 minutes and mean energy drawn from the grid of 2.7 kWh and 3.22 kWh [6]. Efficiency gains of Level 2 EVSE will be most apparent at locations that generally have a dwell time of less than 2 hours such as retail destinations. In contrast, workplaces and residences often have considerably longer dwell times, although the efficiency gains of Level 2 charging were observed across all charge durations and temperatures. Data from the EV Project, a multi-year DOE-funded project to track EV driving and charging behavior across 12 cities and states across the US show that between 74 and 80% of EV charging is done away from home [7]. Away-from-home charging thus presents a sizable proportion of EV energy usage.

Due to limited sample size, we were not able to examine combined effects of temperature and charge duration, but such effects on efficiency may be sizable and should be considered in future research. Further data collection can clarify the effects of ambient temperature on Level 1 and 2 EV charging efficiency, especially at lower temperatures. Energy savings of Level 2 EVSE may vary seasonally and may be greater in hot or cold climates.

V. Conclusions

We observed a consistent efficiency gain in use of Level 2 EV charging over Level 1. Future research should further explore of the effect of climatic conditions, and the relative efficiencies of DC Fast Charging and wireless charging. In addition, there may be meaningful variation in charging efficiency among vehicle models.

Further characterization of EV charging efficiency can inform how EVSE should be included in utility efficiency programs in the future.

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References

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