33rd Electric Vehicle Symposium (EVS33)
Portland, Oregon, June 14 - 17, 2020

Electric Vehicle Managed Charging in the Real World

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Summary
Ever wonder where people charge, how they use their EV's, and what impact that has on the electric grid? FlexCharging has data from EV drivers, and has been doing managed charging since 2017. What design constraints, implementation challenges, and operational hazards present problems for managed charging? How do drivers interact with their cars and where do they charge? What should a utility model in their Integrated Resource Plan? What lessons should be applied to managed charging systems?

Keywords: smart charging, electric vehicle (EV), load management, battery management, user behavior

1 Introduction
Electric vehicle adoption is increasing worldwide, motivated by a mix of energy independence, environmental concerns, and vehicle performance. Utilities must be prepared to provide enough energy throughout the day, and power at the right times of day to charge vehicles. When electric vehicles are a novelty, this is not a concern, but electric vehicles can become a substantial portion of a utility’s load. If a utility has 10,000 Tesla vehicles in their service territory charging simultaneously at the worst time of day at home, that could add up to 96 MW of power, needing about 116 MWh of energy per day. This is the initial adoption for utilities. Some utilities may have 500,000 vehicles in their service territory, and over time many of those will become electric. Assuming total vehicle electrification and a half million vehicles, utilities may need to provide 5.8 GWh of electricity, and in a pathological case, up to 4.8 GW of capacity for electric vehicles alone. This is just focused on light duty vehicles charging at home, ignoring electric buses, trucks, ships, and the impact of DC fast chargers.

If drivers plug in and charge cars when they get home, this could substantially increase evening peak loads, requiring utility capacity additions. While time-of-use electric rates attempt to mitigate the capacity needs, they often encourage drivers to charge at the start of off-peak times, meaning you may have 10,000 vehicles starting to charge in the first minute of the off-peak time. This additional ramp rate provides another challenge for utilities; many power plants cannot be brought online within a minute. Distribution grids may become overloaded, requiring substantial upgrades to feeders, transformers, and substations. A future electrified truck stop may require 20-50 MW of power in the future, requiring half a substation to meet its load.

While most of that charging will not happen simultaneously, even spreading that charging out by 6 hours means substantial additional capital expenditures for capacity and distribution grid upgrades. Systems must be put in place to control load. Time of use rates have limits, with utilities reporting wildly varying ranges of compliance, from ~15%, 31% from historical data, and maybe close to 85% with well-crafted incentives and utility programs.
But even with high compliance, load is shifted to a static rate schedule that might only be changeable once every one or two years. There is no opportunity for energy arbitrage or avoiding renewable generation curtailment. Demand response is an option, however many DR programs are designed to call resources perhaps only 6 times per year, and do not control charging on a daily basis to minimize costs. Demand flexibility uses control technology to shift electricity demand to different hours of the day, while still providing energy services (such as charging an electric vehicle). Demand flexibility is the right conceptual model for managing EV charging. The Rocky Mountain Institute found “residential demand flexibility can avoid $9 billion per year of forecast U.S. grid investment costs-more than 10% of total national forecast needs-and avoid another $4 billion per year in annual energy production and ancillary service costs” [1].

2 FlexCharging Smart Charge app and EnergyNet Service

FlexCharging’s EnergyNet aggregates electric vehicles to provide Demand Flexibility as a service to utilities. FlexCharging’s EnergyNet controls vehicles using automakers’ connected car API, requiring no additional hardware, as described in Fig. 1. This software-based approach makes it easy for drivers to sign up for our service.

Figure 1: FlexCharging Connected Car Control pathway

2.1 A Car is Not a Dishwasher

Managed charging must encompass the needs of the driver first, then the needs of the utility second. Cars are too central to work, life, and our ability to handle emergencies. Demand Response programs for air conditioners, furnaces, and dishwashers are not an acceptable starting point for controlling a driver’s mobility. Any solution that only works via smart EVSE without being able to check the state-of-charge (SoC) from the vehicle is bound to one day fail to meet a driver’s availability expectations for their vehicle, and they will likely withdraw from any program and speak poorly of their experience. Instead to boost acceptance, managed charging must be tailored around the driver’s needs and schedule, and must be done with an awareness of the vehicle SoC.

To this end, FlexCharging has a Smart Charge app available for iOS and Android that allows drivers to register with our EnergyNet service, enter in their schedule and various constraints, and opt out of smart charging temporarily. The app supports an emergency charge level, a minimum SoC for battery health, and a daily schedule for capturing scheduled departure times. We anticipate expanding this over time, though trading off functionality vs. the cognitive load necessary to use the app is a delicate balance. We only manage charging at charging locations defined by the driver in the app and where the driver explicitly allowed managed charging. This alleviates concerns about behaviour at DC fast charging stations or a hotel during a cross-country trip.

The FlexCharging app also allows users to opt out of managed charging in 5 different ways, from a “Start Charging” button, to disabling managed charging or disabling polling for the vehicle, to interacting with the car...
itself. By monitoring the car and using an old-school AI system for modelling driver behaviour and intent, we can detect when people intended to opt out but did not tell us.

2.2 Operational Hazards

Managed charging runs into high-level challenges where some solution is necessary to improve adoption and retention of drivers. Here were the most interesting ones.

2.2.1 Public Safety Power Shutoffs

Drought conditions in California affected the distribution grid in large parts of California in 2019. To mitigate the potential for utility equipment sparking fires, utilities simply shut down parts of the distribution grid, often with roughly 24 hours notice. Managed charging needs to be aware of public safety power shutoffs (PSPS) to ensure that drivers’ availability constraints will be met even if their home may lose power for an unknown amount of time. There is no industry standard way to receive notifications for a PSPS, and tools need to be designed for device aggregators. The utility industry must do more to describe this risky uncertainty to demand flexibility services and other load control providers. We have some ideas on how to start here.

2.2.2 Power outage prediction

More generally, we need a reliable power outage predictor. This should encompass weather at the charging location (ie, snow), and weather that over a larger area can create additional power outages (such as wind storms taking down transmission lines for a large geographic area, or resource adequacy issues in a utility service territory). The goal is to lessen charging time requirements on drivers in the middle of an evacuation.

2.2.3 Level 1 Charging Policy

We had a substantial number of residential users who were charging on L1 chargers, accounting for 1/6th of our charge sessions. Our belief going into this project was that L1 charging is so slow, people will not want us to manage their charging. We also assumed their charging power was so low that it was not interesting to a utility. So all L1 charging did not participate in managed charging. As we spoke with utilities, it became apparent that they desired to manage L1 charging, and we realized the prevalence of L1 charging among our drivers. Vehicle efficiency also improved, meaning a newer EV can get almost 70 miles range when charging for 12 hours instead of 50. We changed this policy, but not in time to show a substantial result for publication.

2.3 Implementation Challenges

Implementation challenges with a managed charging service over connected car API are outside the common experience for the utility and automotive industries.

2.3.1 Internet Connectivity

A connected car needs Internet connectivity, either via a vehicle telematics unit built into the car (ie a cellular modem) or a WiFi connection where the driver has configured the car to connect to WiFi with the right password. Internet connectivity is not a given when you are four stories below ground in a parking garage, or when driving through remote, mountainous terrain. It’s unclear whether 5G cell towers will solve this problem, or amplify it. 5G requires a much denser mesh of towers. While that will be built in the urban core, it remains to be seen whether a large number of 5G cell towers will be built in the mountains, where today’s 4G coverage is spotty.

One option for improving connectivity is for charging network operators to install free public WiFi at affected locations. In remote locations with no Internet or certain urban canyons, consider installing a cell tower nearby.
2.3.2 Automaker API changes

Additional changes come from tracking automaker API updates. Some automakers revise their API frequently to keep up with a very fast pace of innovation. That is necessary to support their pace of innovation, but it does lead to things being occasionally broken. There is no standard for connected car API’s at this point in time, and it probably is not reasonable to push for one until automakers fully encompass light-duty and heavy-duty vehicles (including motorcycles, buses, and semi-articulated trucks).

The Tesla API is a moving target, with new updates released as frequently as every week. A Tesla-introduced regression may be here today, gone tomorrow. Other regressions are more permanent – a 2014 Model S returns vehicle options indicating the car is a Model 3. This broke around August 2019 and requires a workaround.

2.3.3 Automakers Don’t Yet Realize Connected Cars are Platforms

An ecosystem of apps is developing around vehicles, using automaker connected car APIs. In the software industry, applications couldn’t exist without a platform maker building & supporting a platform, with the goal of attracting as many apps as possible to increase the value of the entire ecosystem. The platform maker captures a very small percentage of the total value of the ecosystem, but is remunerated for their efforts if the ecosystem is large with compelling value to users.

Automakers may find it in their enlightened self-interest to provide some basic documentation for their APIs, usage rate constraints for developers, and security work. Notably, using OAuth2 allows a three-way handshake between the driver, an app developer, and the automaker. But this requires some server authentication work on the automaker’s part to allow trusted third party apps to authenticate without obtaining the driver’s credentials. With some minimal thinking of vehicles as a platform for a new ecosystem, a new breadth of apps interoperating with cars will become possible while remaining secure.

2.3.4 Energy Drain and Adaptive Polling

Understanding driving patterns and charging patterns requires frequent polling to get a high-fidelity pictures of vehicle state, on the order of every 2 minutes while driving. Getting data from connected cars requires polling the car’s computer for the vehicle’s current state. While parked and off, polling the car wakes up portions of the car’s computer(s) to process requests. This adds to the phantom load in the vehicle. When a vehicle is off, energy is lost due to battery chemistry (influenced by temperature), serving on-board energy needs like recognizing whether a key is nearby, powering a vehicle’s security system like Tesla’s Sentry mode, and by attempts to wake up the vehicle computer. To minimize this load, FlexCharging collects data on vehicles by polling in an adaptive fashion, based on where the vehicle is located, the driver’s schedule, and whether the vehicle is plugged in.

While the energy usage is difficult to measure due to limitations in the vehicle’s reporting (we encourage automakers to report SoC as a float, not an int), a reasonable initial attempt at adaptive polling amounted to about 200 Wh/hr of energy drain in a 2018 Tesla Model 3 Performance vs a baseline drain of approximately 80 Wh/hr. This adds 11.5 miles of energy lost per day for a vehicle that is left alone for a full 24 hours. This was unacceptably high for some drivers, and led to algorithmic improvements to reduce that delta. This same drain was not noticed by Model S drivers, in part due to the lower efficiency of older Model S drive trains (pre-Raven).

The Model 3 is more prone to additional load because it has a smaller battery capacity. However, the Model 3 is more prone to losing energy quickly, where a Model 3 without polling enabled can lose 10 miles of range in 2 hours unexpectedly. We observed energy loss rates of 770 Wh/hr for 4 hours with no clear reason (equivalent to 12.5 miles). We monitored for keeping the climate control on (including “dog mode”), attempted to correct for temperature and wind effects, Sentry mode, whether seat warmers were on or whether a door was left ajar, and sampling effects caused by Tesla using an int to report SoC instead of a float (ie, both 89.0% and 89.9% show up as 89%, introducing errors due to the loss of precision). Our attempts to quantify this are akin to the famous Millikan oil drop experiment to determine the charge of an electron – try & try again, and look for the smallest deltas. We are left with only supposition, but this energy loss could be the car’s computers downloading updates (near weekly), or some aspect of the battery management system (such as thermal management).
With improvements to FlexCharging’s adaptive polling algorithm, our incremental energy load is between 10 Wh/hr and 43 Wh/hr (1-4 miles/day). While not large, it is between 12% - 50% more than the Model 3’s own energy drain. Further enhancements using AI and/or driver calendar app integration might yield better results.

2.3.5 Consumer app support

Consumer-friendly apps need to clearly set driver expectations, and the complexity of a full managed charging solution is larger than it first appears. While we have a complete, functional UI that benefited from many user-suggested improvements, we are rewriting the UI based on user feedback gained over the past two years. This will improve usability and educate drivers on the metrics relevant to EV’s, such as energy used and dollars per mile driven. The app will show charging session history so users can better grasp charging time, costs, and eventually carbon footprint. Drivers may not fully grasp that unlike fueling a gasoline car, their car costs different amounts to fuel at different times of day. The best way to handle this complexity is by doing the right thing all the time by default in software, after capturing driver constraints.

3 EV Driving and Charging Data

FlexCharging’s polling produces status events describing what a vehicle is doing. From these status events, we construct charge sessions, charge intervals (every 15 minutes of a charge session), trip segments, dwell times, and identify data gaps. FlexCharging identifies charging location types based on a combination of user input, data from the EV, and an offline resolution process. With these pieces, we generate load profiles for drivers in aggregate, as well as identify at what type of location they are charging at.

3.1 Vehicle Telematics for the Win

This wholistic view of an EV lifecycle requires a vehicle telematics solution, and lets utilities fully grasp the impact of EV’s within their service territory, as in Fig. 2. A utility in Salt Lake City would have no clue about their drivers driving to Las Vegas, charging at DC fast charging stations along the way. The percentage of corridor charging (at DC fast chargers or Tesla Superchargers) may vary with driving conditions and will be seasonal, reflecting whether people are making road trips vs. getting snowed in.

![Figure 2: EV Data Dashboard showing load profile and charging location types per program](image)
Dwell time data identifies where a vehicle sits idle but does not charge. This is useful for charging network operators and utilities to site new charging stations. It could also identify employers where workplace charging would be beneficial today, or potentially should be scaled up to adequately serve demand. Trip segment data includes the vehicle SoC, and could indicate where new corridor charging locations should be installed.

Charge session data describes when drivers are charging, their power level, and energy added. This data informs load profiles for utilities, suitable for including in Integrated Resource Plans. This data will be seasonal, reflecting cold weather energy loss, heating needs, air conditioning, and longer road trips in the summer. Collecting a full year’s data provides a more comprehensive picture, to understand impact on summer and winter peaks.

3.2 Driving and Charging Observations

The EV load shapes in Fig. 2 vary substantially, but so do the drivers. One set of drivers is primarily transportation network company drivers, using their vehicles similar to taxi drivers on a regular basis. A portion of drivers in the first set opted out of managed charging at home, or didn’t enter a home charging location during sign-up. The lower three load profiles do show little charging during evening peaks, with a large proportion of charging shifted to 10 PM or later, based on utility rate schedules.

Note that residential charging only accounted for 71.6% of energy added into electric vehicles, and we believe our data shows substantial more corridor charging than previous studies. Cars became longer range and charging networks expanded, so driving patterns changed as well. Data is going to be specific to different utility service territories and will continue to shift over time, and so must be refreshed regularly to track market conditions.

Beyond expanded DC fast charging networks, what was the primary variable that might explain differences? One astute observation from Northwest Power & Conservation Council staff was that the efficiency of vehicles will increase pretty quickly from the initial Model S numbers towards the low 200 Wh/mile range (or better than 4 miles/kWh). Tesla Model S efficiency improved from about 330 Wh/mile to 256 Wh/mile today, a 22% improvement in 6 years. Similarly, the Model 3 efficiency improved by 3.8% in the two years it has been out. When these efficiency improvements arrived, Tesla held the battery pack size constant, increasing the range of the electric vehicles to just shy of 400 miles for a Model S. This defines a new set of expectations for the marketplace. It is worth noting that no automaker has released a car with more range than the 2013 Model S with an 85 kWh battery pack. What Tesla is producing today, the rest of the marketplace will be doing in 2-5 years, so studying Tesla-centric results is well-aligned with predicting the future. Fig. 3 shows efficiency as a function of model, speed, and temperature.

Additionally we can analyze trips to get a feel for where people drive. For a utility, understanding the reality of long-distance road trips reinforces the importance of corridor charging. This provides insight into what loads are not shiftable, both by drivers who live in a utility service territory and potentially by drivers passing through a utility’s service territory. Past research dismissed frequent long distance trips, thinking someone who drove to Las Vegas every weekend was an outlier. We suggest a small portion of drivers that make long-distance trips is the norm, and expectations must be updated to account for corridor charging.
Figure 3: EV dashboard with efficiency vs model, speed, and temperature, as well as detailed trip segments.

FlexCharging also tracks charging location types in a fine-grained manner, differentiating between locations like shopping, movie theaters, hotels, medical facilities, airports, workplace charging, and casinos. These all inform a richer view of how drivers use their vehicles and where they charge, and may suggest other similar charging locations for new EVSE. These are also grouped into categories, for higher level summaries. Fig. 4 shows the energy added based on charging location type. The bottom left breaks up charging sessions based on whether our app took a control action (like starting or stopping charging).
Fig. 5 summarizes driving for many of our drivers over the span of nine months. 71% of charging was done in a residential setting (home, apartments, vacation homes, and other people’s homes such as visiting family for holidays). 20% of the charging was at corridor charging locations, primarily Tesla Superchargers. Workplace charging was 8%, while public charging was 6%. Also the geographical distribution of charging locations reflects cities and corridor chargers along highways.
3.3 A Closer Look at Public Charging Location Types

FlexCharging tracks detailed charging location types to gather better insights about charging. For simplicity we group them into categories: residential, workplace, business, public, corridor, and travel. See Fig. 6.

Utilities and charging networks may be very interested in the common types of charging locations observed in the data, to understand where to build new charging stations or to understand utilization based on our Tesla-focused drivers. Fig. 7 shows a very small percentage of non-Tesla DC fast chargers (only 15 charging sessions out of over 7000 were at DC fast chargers). Note we do have a reasonable percentage of Nissan Leaf drivers. Among some Leafs and many Tesla drivers, CHAdeMO chargers are barely utilized.

4 Managed Charging Potential

Managed charging provides the opportunity to turn an armada of cars into a Demand Flexibility resource, minimizing both costs and emissions. While static rate schedules provide a starting point, for best results this requires dynamic prices, as well as marginal CO2 emissions data. Price-wise, static TOU rates may vary by up to 10x within a day, with potentially larger changes in the spot market. Emissions-wise, WattTime believes the CO2 emissions forecast will need to be updated several times throughout the day to reflect constantly changing grid conditions. One day perhaps demand response events could be subsumed by frequent changes in a dynamic
price schedule, reevaluated hourly or even every 5 minutes (similar to existing DR scheduling windows on the Western Energy Imbalance Market).

Beyond this, as electric vehicles become a substantial percentage of a utility’s load, managed charging must be done for an entire set of vehicles at once. Rules for one vehicle are beneficial when done individually, but pathologically cause grid problems if every EV follows the exact same set of rules (a third peak with a high ramp rate). Managing charging should be applied to all commercially interesting EV makes and models within a utility balancing authority, and cannot be done by one automaker alone (unless it produced a majority of the purchased EV’s in a market). Scheduling charging then looks similar to scheduling Big Data batch processing jobs in Hadoop, with comparable capacity management and service level agreement constraints. Reducing renewable energy curtailment is analogous to opportunistic tokens from the Mercury scheduler – free bonus capacity. [3]

However there are limits to when charging can be flexibly shifted. Driver needs must come first, or they will not accept managed charging. This requires looking at the vehicle state-of-charge, the user’s schedule, and the time required to charge at the current location (ie, the power for L1, L2, high amperage L2, or a DC fast charger can vary by 13x, and vehicle efficiency currently varies by 45% from one auto manufacturer). Our app allows drivers to opt out of managed charging in multiple ways, both temporarily and permanently.

On top of these behavior-based conditions, corridor charging and any charging location not programmed into our app are assumed to disallow flexibility. Core to our model is that users must opt into shifting charging in the FlexCharging app, and primarily they only do this at home. If someone parks at a Tesla Supercharger they want to be able to leave in roughly 30 minutes, not sit around for hours waiting for the local utility’s off-peak times. Until just recently, we did not shift charging at L1 charging locations, due to the low power levels.

With these constraints, Fig. 5 shows load profiles where we took a control action, vs did not. The top left graph shows more energy shifted from evening peak times towards 10 and 11 PM. The graph below it shows the unshiftable charging locations (because of type, driver opted out, or charging on L1).

Fig. 8 shows drivers from our multiple partners with a different proclivity for managed charging. Apps should emphasize temporary ways to opt out of managed charging, vs permanent means.
Fig. 8 illustrates patterns between our different driver groups. Our “organic” drivers discovered our app on their own, while partner 1 consists of transportation network company drivers. Those drivers showed more apartment charging than our organic drivers, who generally skewed towards more expensive Tesla vehicles (Model S and X vs. Model 3). However it is hard to make generalizations with our current sample size, as there is a wealthy retired person who drives their Model X and pick up passengers simply to have something to do.

4.1 Improving Managed Charging Acceptance

Today many utilities do not have time-of-use rates. As such, the number of people that will rearrange their life for the benefit of their utility is not high. The time-of-use spread needs to be high enough to incentivize change. For utilities without time-of-use rates, providing a similar incentive (perhaps as an annual gift card) will help encourage driver adoption. Effective utility rate design should learn from SEPA's best practices [2].

Additionally the user experience is surprisingly challenging. Getting managed charging right involves more complexity than you might initially think, given that in the end all we’re doing is turning charging on or off. The right UI with clear constraints and feedback is essential to improving user adoption and appreciation for the benefits provided by managed charging. After that, there is even more complexity to model user intent. At FlexCharging, we are redesigning our user experience based on feedback to better meet drivers’ needs.

4.2 Increasing Flexible Load

Fig. 5 shows some effect from managed charging, but we anticipated a larger effect. This problem only became apparent during analysis. We had charging sessions that were at the evening peak for a utility, but we treated them as off-peak. Many drivers are on rate schedules that do not define on-peak times – they simply bill users based on volumetric energy consumption (kWh). As such, there is no concept of peak vs. off-peak times from the driver’s monetary perspective. If a demand flexibility system uses the rate schedule alone to decide whether to shift charging, the absence of time-of-use rates leads to undesirable charging that may otherwise be shifted. A supplemental default charging policy per utility can mitigate this, by charging starting at an off-peak time across all rate schedules. Alternately, dynamic pricing or carbon emissions provide another signal to shift charging.

Among our drivers, 74% of charging locations were configured for managed charging, based on driver input. However, only about half of the charging locations had rate schedules selected by drivers, and half of those had non-TOU rate schedules. We augmented this by defining a default charging policy for utilities (using either utility published guidance or the intersection of off-peak times among the utility’s common residential rate schedules), which increased the number of shiftable charging locations with some intra-day price sensitivity from 32% to 96%. We missed 4% of the charging locations.

As discussed in section 2.2.3, L1 charging did not participate in managed charging. We subsequently reversed this policy decision, but not in time for this publication. As Fig. 9 shows, 1 in 6 charge sessions occurred on L1.
Based on initial results, only 40.6% of charging sessions were shiftable. Adding in L1 charging increases that by 16.4% to 57%. Flexibly charging even when the utility rate schedule doesn’t provide a direct driver benefit substantially increases the number of charging locations we would shift load at, and there’s some room for improvement on that front (~4%). An additional factor is our UI design in our initial version. Future studies may be able to flex load for at least 61% of charge sessions, perhaps up to ~80% with the right user experience. Future work will compute driver cost savings and emissions savings.

5 Conclusion

We demonstrated data collection capabilities and analysis, useful for utility Integrated Resource Plans and siting EV charging stations. We reviewed our software-only managed charging solution and early field work, showing which characteristics worked and which require additional engineering effort. Managed charging has a huge potential for utilities to avoid costs from new capacity as well as distribution grid challenges. We have a pathway to shift up to 80% of charge sessions. Combined with dynamic price signals and future work around marginal CO2 emissions reductions, managed charging can make EV charging green and cheap for everyone.

Acknowledgments

Thanks to our partners at Rocky Mountain Power, Forth, EPRI, PCE, and other organizations for their support.

References


Authors

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