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PERSPECTIVES

Building and sustaining reliable public EV charging in the United States

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1. Introduction

The US electric vehicle (EV) market appears to be taking off. EV sales are at record levels in 2022 thanks to both sky-high gasoline prices and the increasing availability of desirable EV models in all shapes and sizes. But the reliability of the public charging infrastructure needed to power these EVs is not keeping pace. Anecdotes from EV drivers report frequent outages, with common complaints including broken connectors and screens, failed user authentication and payments, and chargers that do not deliver their stated power level (see for example Phelan (2022), Plug In America (2022), and Chokshi (2022)). Poor charger reliability reduces the effective driving range of EVs, because drivers are never sure that a charge will be available in the most convenient location, and makes EV ownership less attractive. With substantial public investment being made in EV charging through the Infrastructure Investment and Jobs Act, it is critical that charging stations are built quickly to keep pace with the growing number of EVs on the road, and that these chargers operate with high reliability. However, little progress on reliability has been observed despite increasing recognition that a major problem exists (see, for example, Gitlin 2022, Marshall 2022, Voelcker 2022)—a problem that could well be exacerbated as demand for charging increases, existing hardware and networks become obsolete, and new firms enter the market.

Through conversations and site visits with stakeholders throughout the EV charging ecosystem—original equipment manufacturers (OEMs), charging network operators, hardware and software vendors, utilities, maintenance organizations, governments at several levels, and EV advocacy organizations—we have observed the challenges this open ecosystem faces to create and sustain high reliability. Without a 'chief engineer' to coordinate the efforts of stakeholders in designing and operating the system, and with challenging unit economics and hardware-focused government grants that lead to systemic underinvestment in maintenance, a fragmented charging infrastructure is emerging in which the reliability needs of end users—EV drivers—are neglected. As a result, a rapid and successful transition from internal combustion engine (ICE) vehicles to EVs may be imperiled. Active design and troubleshooting of the EV charging system is needed if the potential of the EV transition is to be realized.

2. How reliable are US EV chargers today?

Answering this question is not easy because comprehensive public data does not exist that allows reliability and root cause analysis to be undertaken across geographies, charging networks and hardware types (i.e. slower level 2 chargers vs. level 3 DC fast chargers). Tesla, the leading seller of EVs in the US today, reports 99.96% uptime for stations in their proprietary Supercharger network (Tesla 2021), and Tesla drivers are generally very positive about their Supercharging experiences. The large public networks that are available to drivers of all EV makes and models claim 95%–98% uptime (still not overly encouraging, representing 7–18 days of downtime per year), but do not provide clear definitions of 'reliability' and performance data to support these numbers. Driver experiences are less positive. A recent field survey conducted in the San Francisco Bay Area found that of 657 Combined Charging System (CCS) connectors at 181 public fast-charging stations, only 72.5% were functional as defined by being able to provide charge for 2 min or more (Rempel *et al* 2022). Similarly, a recent J.D. Power survey found that one in five visits to an EV charging station did not result in a successful charging session occurring (Power 2022). While the veracity of some negative accounts has been challenged by network operators (Lingeman 2022), it is not possible to contextualize where problems do and do not exist without hard data.

The lack of consensus on the current level of system performance is due in part to the lack of a shared definition for uptime. The number reported by Tesla '… reflects the average percentage of sites globally that had at least 50% daily capacity functional for the year', meaning it is a site-level metric that could conceal low-performing chargers. Rampel *et al* (2022), in contrast, tested charging station performance at the plug-level. Analyzing at the charger-level would be yet another possibility, recognizing that some chargers have multiple different plugs (e.g. CCS and CHAdeMO). There is also a lack of agreement of what to include in the calculation of downtime. Should the network operator be responsible for outages due to blackouts? Cellular network outages? Vandalism? The failure of the vehicle to communicate with the charger? None of these are directly or completely within the network's control, and operators may seek to exclude many causes of charging failure from uptime calculations to increase their perceived performance. However, this does not help the EV driver stranded at a broken charger with an empty battery.

Although quantitative evidence is limited, there is broad consensus from all the parties involved, including OEMs, station operators (when they are off camera), maintenance providers, electric utilities, and consumers, that open public fast chargers are not highly reliable. So much so that overbuilding charging capacity in a single hub is a recognized operator strategy for mitigating the unreliability of individual chargers. When a charging site has several chargers and at least some are available, consumers can go from one charger to another in search of a working charger, giving these networks higher reliability at the station level. However, rapid growth in EV adoption in the years ahead may reduce the ability of drivers to try multiple chargers, which may lead to both Tesla and non-Tesla charging networks being perceived as less reliable.

3. Why are broken EV chargers not being fixed promptly?

The causes of charging station outages have been well described generically—hardware breakages, dropped connections, payment failures, vandalism, software issues in the EV initiating the charging session, user error, 'ICEing' of charging stalls by conventional internal combustion engine vehicles, etc.—but not in a way that identifies root causes or enables improvements. It is notable not just that EV chargers have problems, but that owners and operators of this infrastructure are unable to get these chargers repaired in a timely manner.

Many observers attribute the persistence of broken level 2 charging stations to the hardware sales business model of leading vendors, in which they generate revenue from the upfront sale of the charging hardware and from recurring networking fees, but not from utilization of the charger itself. The result is that the vendor has no incentive to ensure that the station owned by the site host is working as intended, absent the existence of a maintenance service agreement. (Problems with level 2 chargers are often traceable to network connections and payments; 'dumb' level 2 chargers that simply dispense electricity have been observed to work maintenance-free for many years.)

DC fast chargers are more technologically complex, and numerous opportunities for failure exist at the interfaces in information and power between the EV itself, the EV charger, the utility, network connectivity, and payment processing (figure 1). Both charging station technologies and EVs are continuously evolving, with increasing charging power levels, new makes and models, and new data sharing protocols such as ISO 15118 for 'Plug and Charge', so new bugs are continuously being introduced. At the same time, network operators appear to have limited appetite for investment in maintenance, which may be explained by the challenging unit economics of public fast charging stations when utilization is low. While it is perplexing that network operators may knowingly forego roughly one-quarter of revenue due to stations being down one-quarter of the time, a perception exists that operators are unwilling to invest heavily in maintenance for stations with low utilization (which is to say, most stations) that could only be built with the assistance of generous government capital grants.

In practice, the ability of network operators to know the status of chargers in real time and the existence of problems is limited to those issues that can be identified remotely, and when network connectivity exists to relay that information. And so the ability of EV drivers to know the status of chargers for accurate route planning is limited similarly. All parties are to a significant extent 'driving blind.' And even if the intent to undertake maintenance exists, not enough trained technicians exist nationally to do this work, a gap that prominent charger maintenance startup ChargerHelp! is working to address.

4. How can we improve system performance?

In discussions with participants in the charging ecosystem, we heard from some that the system will be 'self-healing' as operators work down the learning curve, just as technologies such as cell phones and Apple Maps have in the past. We also heard that the most practical approach to improving system performance is simply to measure performance (as is required of National Electric Vehicle Infrastructure (NEVI) grant recipients) and report it publicly to shame operators into improving their performance.

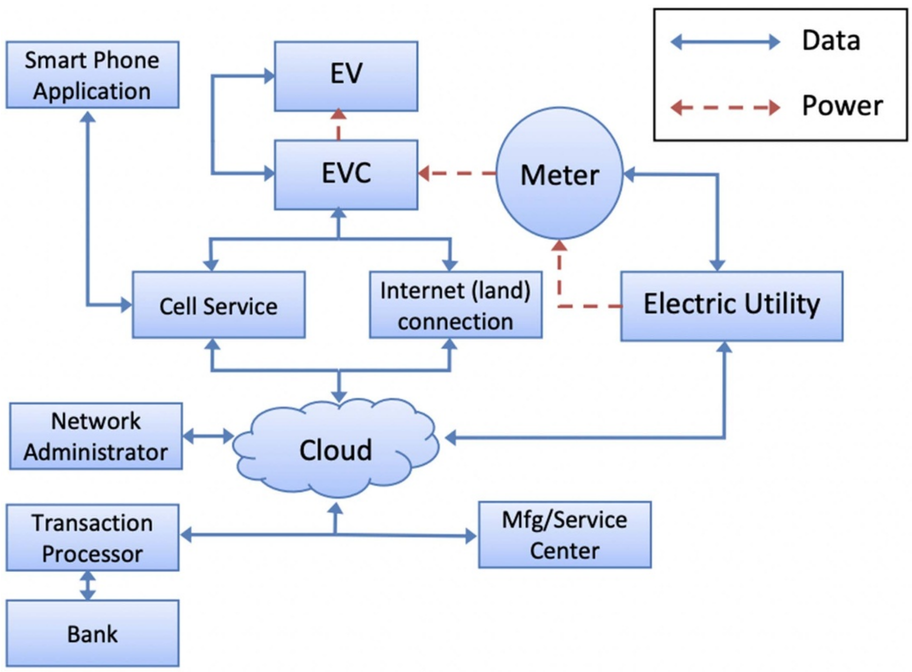

Figure 1. Backend interactions for networked EV charging (CEC 2018). Reproduced from CEC (2018). CC BY-SA 4.0.

Can these approaches really solve the problem? Perhaps they will, but likely not in the timeframe we need. There are plans to add at least 500 000 charging ports in the US over the next 5 years, and to increase the level of EV adoption to 50% nationally by 2030 (and 100% by 2035 in California and other ZEV states). But these optimistic forecasts rely on millions of motorists individually deciding to shift from an ICE vehicle to an EV, supported by a charging network that is sufficiently robust and user friendly. If the public charging network is inadequate to reliably support long-distance EV trips, EV adoption will be mostly limited to those with a driveway or garage who can do most of their charging at home (Lee *et al* 2020), which has significant equity implications, and the majority of drivers will continue to purchase or maintain gasoline vehicles, delaying the EV transition for years.

We believe that ultimately what is needed is a continuing dialogue between the various players in the EV charging ecosystem, each of whom has a unique role to play. This includes:

- EV drivers and planning apps who have the best visibility into how effectively EV charging is working on the ground, and whose voice has been conspicuously absent to date;
- Automakers (OEMs), charging hardware and software vendors, and payments and connectivity providers who implement the various software protocols and handshakes need to achieve a successful charging session, and who are integral to the implementation of fixes;
- Charging station operators who manage chargers in real time, make decisions about how and when to undertake maintenance, and own the high-resolution data needed to diagnose problems;
- Installers and maintenance providers who provide the workforce and know-how to actually solve problems in the field;
- Policymakers who are influential in the deployment and management of EV chargers through the provision of incentives for charger deployment and implementation of performance standards; and
- Utilities whose tariff design and interconnection processes are influential in where chargers get deployed, what technologies are deployed, and how long it takes.

These organizations are in many cases competitors, but they also share a common interest in creating high quality charging that encourages ICE drivers to switch to EVs. So there is an incentive to cooperate if a mechanism can be developed, but no such mechanism for driving reliability improvements currently exists. The key need is to create a working group involving all the participants as a 'virtual chief engineer'. The first step would be to identify the most common types of failures (e.g. authentication failures, payment failures, connectivity failures). These commonly involve two or more of the system participants, which is why individual players struggle to address them. The second step would be to trace the failures to their root causes. The third step would be to focus on countermeasures for each cause, experimenting to find the best countermeasure which could then be shared throughout the group, and then eliminate the causes so that the types and frequencies of failures falls continually. As this happens—moving the charging system much more rapidly down the learning curve—system performance will improve, resulting in satisfied EV drivers and faster EV adoption.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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