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An Integrated Global Philosophy of EV Charging

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Summary

Electric Vehicle (EV) charging methods have evolved over the past two decades to reflect the radical evolution of EVs. In some cases these methods have been of varying usefulness to the EV driver. DC fast charging, which made a brief appearance in the late 90s, is now a valuable EV market enabler, but suffers from the political and technical disagreements of multiple protocols. Globally, EV charging will evolve further to meet the demands of the new consumer EVs and the demands of the EV driver. This paper proposes an integrated global philosophy to meet these demands.

Keywords: BEV (battery electric vehicle), driver, battery charge, fast charge, infrastructure

1 Introduction -- Needs of the EV Driver

The needs of the EV driver are relatively simple. She doesn't want to go to a gas station ever again and likes the idea of charging in her garage overnight or at work during the day. If she has to take a long trip, she'll be okay with stopping for ten minutes for a fast charge every hundred miles or so, maybe thirty minutes every two hundred miles to get something to eat. She doesn't care about communications or hardware protocols. She just wants to charge her EV with no hassle.

Methods of Electric Vehicle (EV) charging have evolved to serve the ever-changing consumer EV landscape over the past two decades with varying effectiveness. The focus here will be on the needs of the EV driver and what the EV charging picture will look like to meet those needs.

2 A Brief History of EV Charging Infrastructure

The 1990s saw the first real introduction of EVs with the GM EV-1 and others such as the Toyota RAV-4EV and the Chevy S-10. The EV-1 and RAV-4EV used induction paddle chargers—not the same ones by the way. Thus, even back then political and technical disagreements imposed different charger requirements for the same class of EV, even though supposedly governed by SAE J-1773 inductive charging protocols. Eventually they resolved this difference. Other vehicles at the time used conductive charging schemes based on J-1772 and use of the Avcon connector. By the late 1990s, AeroVironment, Inc. developed a 60kW direct current (DC) fast charger, but had to work closely with Underwriters Laboratory to create a new listing standard since this was new technology.

Figure 1: 1998 DC Fast Charger

Over the next decade, the electric material handling fork truck and airport ground support equipment movement accelerated dramatically, while the EV market stalled. This new movement allowed charger manufacturers to gain experience with DC fast charging and to apply lessons learned from working with electric utilities and development of supply chains when the new EV market began to develop. However, the AC Level 2 (European mode 2 and mode 3) market didn't pick up again until the driving force changed from air quality legislation to high energy prices. The J-1772:2009 and IEC-62196 standards appeared and the new

wave of EVs also appeared, namely the Nissan LEAF™ in December 2010 and the Tesla Roadster. While the J-1772 Level 2 standard was very effective in preventing proliferation of connector types and communications protocols, the same wasn't the case for the new incarnation of DC fast charging.

The Recent History of DC Fast Charging, c.2010-2015. How is it we have CHAdeMO, SAE, GB, and IEC DC fast charger standards, and Tesla's proprietary DC connector? IEC for Europe and GB for China makes sense because of the large geographical and political territories they cover. However, the story of the fight between the CHAdeMO and SAE Combo protocols (documented abundantly in blogs and magazines), and then later the Tesla Supercharger protocol entry, is a case study in political and technical positioning.

3 What Kind of EVs Will We See in the Future?

In the case of plug-in hybrid electric vehicles (PHEVs), the charging infrastructure answer is relatively easy: AC Level 2 residential and workplace charging at low power (120V/240V).

The full battery electric vehicle future picture is less clear, with many OEMs making claims of future vehicles with 200, 250, even 350 mile ranges between charges. The 100-mile EV, as exemplified by the Nissan LEAF, Kia Soul, and BMW i3 has a well-established model to support charging with 30A Level 2 (7.2kW at 240V) residential and workplace charging, and fast charging at the 50kW level using CHAdeMO or SAE. However, while this model has been sufficient to support the latest push for modern EVs, such low power charging doesn't allow for OEMs to push the limits on reducing charge time or increasing range which would better suit the needs of more drivers.

Tesla, who currently markets a Model S version with a 250-mile range, enables their EVs to be DC fast charged using the Tesla Supercharger network at 120kW power level. But thus far OEMs who have also made promises of longer range vehicles, such as Volvo, GM and others, have yet to specify the power level or protocol, other than CHAdeMO or SAE.

4 An Integrated Global Philosophy of EV Charging

Three primary modes of charging will serve the global EVs of the future:

1. In-Trunk Cordsets
2. Residential and Long Dwell-time Charging (includes workplace and multi-unit dwellings)
3. DC Fast Charging

Figure 2: TurboCord Dual Voltage Cordset

4.1 The In-Trunk Cordset

In-trunk cordsets serve the basic need of the EV driver to have a portable charger available when they're both home and away and don't have access to a public charger.

The global philosophy for in-trunk cordsets for OEMs will be a single controller platform with plugs and connectors specific to the region at the 200 to 240VAC voltage level, depending on the country. The North American and Japanese markets, however, will likely be served by a dual voltage cordset of Level 1 at 120VAC (100VAC for Japan) and Level 2 at 240VAC. Different markets will require different features to comply with safety standards. For example, the EU market will likely require DC leakage protection, while the Asian market may require overcurrent protection.

4.2 Residential Chargers

Residential charging is widely considered the most important and most frequent venue for EV charging, with estimates of 80% of all charging happening in a residential setting. Public charging plays a less important role [1] [2].

Figure 3: Residential EVSE

In the US, residential chargers for EVs are typically served with 16A (3.8kW @ 240V) and 30A (7.2kW @ 240V) for Level 2 and with 120V for Level 1. The US and Japan are unique relative to the Level 1 low voltage service. For much of the rest of the world, higher voltage service of 200 to 240VAC, depending on the country, is the primary residential service available.

To date, residential chargers have been almost exclusively non-networked. With the advent of networked chargers connected to home area networks, networked chargers are now more economical than they have been before, and provide increased functionality, including grid services for the local electric utility or power grid.

4.2.1 Multi-Unit Dwellings

Figure 4: Multi-Unit Dwelling EVSE Installation

Multi-Unit Dwellings (MUDs), such as apartment buildings and condominium complexes, often represent a large percentage of the population in a given area. For example, in San Diego, CA that figure is approximately 50 percent. For many other places in the world that percentage is much higher, meaning it is crucial to overcome the difficult and unique obstacles that MUDs face when installing EVSE. These obstacles include: working with home-owner associations (HOAs), limited electrical service, solving installation difficulties and costs, separate metering, common area EVSE and fees. The California Public Utility Commission (CPUC) is developing a sub-metering program that would use a third-party meter data management agent (MDMA) to provide billing and meter data for MUD tenants and others through the use of networked EVSE. Other MUD charging solutions include integrated energy storage, and government incentive programs.

4.2.2 Workplace Charging

In many cases workplace charging could be an alternate to, or even an extension of, residential charging. For example, if an EV driver parks on the street at night and has no access to a charging station, she may view the workplace as her primary place of charging. If the employer allows their employees to charge for free, then the workplace is a true extension of charging at home. However, the future may see a higher percentage of employers charge their employees a fee for charging, which may limit use to EV drivers with long commutes and to those without access to home charging.

Electric utilities view charging at MUDs and workplaces as potential venues for grid services, such as demand response. This is especially important for utility service areas with increasing penetration of renewables such as wind and solar. In the case of workplace charging this could potentially mean cheaper, more effective charging than residential charging.

4.3 DC Fast Charging

DC Chargers currently in use come in power levels from 24kW public chargers to 500kW electric bus chargers. The idea of 10kW to 20kW DC residential chargers has been proposed by OEMs as a way to provide a quicker charge than traditional AC Level 2 and to lower the EV MSRP. However:

- Residential charging is a long-dwell time activity and typically doesn't require higher power levels.
- Electric utilities aren't fond of residential high power charger levels above 10kW.
- The residential electrical service is more likely to require a costly major upgrade.
- The cost of a 10kW DC charger is projected to be a factor of five times more than a 9.6kW AC Level 2 charging station.

Figure 5: Tesla Charging at a 50kW DC Fast Charger

The real value of DC charging is in corridor use. Corridor chargers can be located in a city or at highway exits between cities. The effectiveness of corridor charging can be measured in miles per minute of charging. For example, a 120kW DC unit at a Tesla Supercharger station can provide 60kWh in thirty minutes, or about 180 miles of range for a Tesla at 3mi/kWh.

On the whole, 50kW for DC fast charging using the CHAdeMO, SAE Combo, or IEC Combo protocols is not a terribly useful power level for applications such as corridor charging. The charge time is 30 minutes for a range of only 60 miles for an EV such as the Nissan LEAF. Typically, as much time is spent driving to the charger and then charging than is spent on the road. 24kW DC chargers are even less useful in that respect.

The business case for DC fast charging is directly tied to port capacity factor, which is the amount of usage a port receives. The business case is also tied to kWh throughput. The best business case is high capacity factor with high power chargers. For example, a DC fast charger with a higher power level, of say 120kW versus 50kW, enables the EV driver to get more recharge miles per minute. This provides a more compelling business case for the station owner than a lower power charging station as long as the capacity factor is high. Availability of multiple ports also allow for high use times (e.g., holiday weekend travel back to the city), but are a liability when usage is low (e.g., late night weekdays. Currently, networks of DC fast charging stations have one and sometimes two DC ports, while the Tesla Supercharger network has up to eight ports. Tesla has done this so that EV drivers will have less queueing time. From a utility perspective a Tesla Superstation isn't provisioned for 960kW of service because it is unlikely all eight ports will be charging EVs simultaneously at full power. Typically, some EVs will be near the end of their charge (much lower charge rate) when others are just starting their charge session.

The placement and number of DC fast chargers for corridor charging will change with the type of corridor and with an increasing number of EVs. For example, charging stations on corridors such as the I-5 in Northern California, may be served with two to four ports due to the low volume of traffic, even when EVs comprise a high percentage of vehicles. High volume corridors such as between Los Angeles and Las Vegas will require stations with many ports. However, the number of ports will still have to be optimized to balance the tradeoff between peak and low traffic volumes to justify the business case.

4.3.1 DC Fast Charging for the 250-Mile EV

The argument for a 250-mile range EV is that the EV driver would rely less on EV charging infrastructure away from the home charger. Such an EV could make the roundtrip journey from Los Angeles to San Diego (on the I-5) or the one-way trip from London to Manchester (on the M40) without recharging. If all future EVs had that capability then the need for and utilization of corridor chargers would be less important contributor to the needs of most EV drivers.

Tesla has demonstrated this type of vehicle and the capability to accept a charge at the 120kW power level, taking about 45-60 minutes to recharge. With a range of over 200 miles, which may take about three hours

of driving time, a one-hour rest stop every three hours isn't unreasonable. The 50kW power level requires more than twice as long to charge a 250-mile EV than at the 120kW power level. Not only is this very inconvenient for the EV driver, but can create a queue of EV drivers waiting to charge if enough ports aren't available.

4.3.2 DC Fast Charging for the 125-Mile EV

The argument for a 125-mile range EV is that the driver has a more affordable vehicle that has better charge time performance—ten minute fast charging. However, ten-minute fast charging requires a battery capable of accepting a 200kW charge. This type of battery has very high cycle life, calendar life, and excellent safety characteristics and is in production by many large battery manufacturers worldwide. It is in wide use for grid energy storage [3] and electric buses [4] [5] and has also been incorporated into some EV sedans on a limited basis (e.g., Honda Fit). While this type of battery has a very high specific power, which allows for very high charge rates, it has a low specific energy, which makes it as heavy as the battery in a 250-mile EV. A connector standard for this higher power level would need to be adopted. A potential candidate is an extension of the SAE/IEC DC connector.

For corridor charging, the 125-mile EV driver spends a quarter of the time at the charger than that of a 250-mile EV driver, even though the 125-mile EV driver would have to stop twice as often on a long trip. However, the queue time per port is also much shorter for a 200kW charger. The charger is more powerful, but fewer ports may be needed on a corridor because of the shorter queue time, resulting in potentially less peak power required for the utility service.

A high volume case would be the I-15 corridor between Los Angeles and Las Vegas, which has an approximate peak hour traffic volume of 5,400 (one-direction) of which 20% is truck volume [6]. For ten-minute fast charging and a penetration rate of 5% EVs in 2025, this translates to thirty-four 125-mile EVs requiring a recharge once during the trip. One solution would be to install a 34-port, 200kW per port charging station (7MW) near Baker, California to handle the corridor's peak requirement. Existing EV charging station networks aren't constructed this way. Instead, the today's stations are distributed at 20-mile intervals [7]. However, this calculation provides an order of magnitude requirement for ports.

As a reality check, the approximate 250-mile distance from Los Angeles to Las Vegas would require about 71 kWh per EV (at 60 mph), or about 300MW total peak utility service if every sedan were an EV—in say, 2040. A portion of this peak utility service could be mitigated to an extent via energy storage depending on station utilization and location. Also, much discussion has centered on mass transit options for popular routes that would potentially limit the requirement for fast charging stations. As a side note, a gasoline-powered vehicle would require approximately 170 kWh (at 50 mpg), while a fuel cell-powered vehicle would require approximately 177 kWh (Toyota Mirai at 47 mi/kg hydrogen), which demonstrates the major efficiency advantage of battery EVs.

A 250-mile EV could make the full trip without recharging (with low speed driving), but the charging station at Las Vegas would require over a hundred ports to minimize queueing time. A 60-mile EV (50kW charger) would require several stops with several hundred ports along the way.

5 Conclusions

Residential charging (including MUDs), and to a lesser extent workplace and other long dwell time charging venues, will remain the dominant location for EV charging because of convenience, pricing, and the potential for grid services. The two cases for future EVs, 125-mile or 250-mile have advantages and disadvantages. For example, the 250-mile EV will require longer to charge, but the longer range is compelling to minimize range anxiety. The 125-mile EV will allow ten-minute charging, but will require extensive high power corridor charging infrastructure.

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