Building the Charging Infrastructure for Electric Vehicles

Robert Huntley, for Mouser Electronics

Around the world the race is on to get us to replace our fossil-fueled vehicles with electric ones – we have all seen charging points spring up in grocery store parking lots, highway service areas and many other public places. The adoption rate of electric vehicles is predicted to climb extremely rapidly, with global stock of electric passenger cars passing 5 million in 2018 and increasing to a projected 250 million by 2030. Such numbers will require a significant change in the number of charging stations available compared to the numbers deployed today. Another consideration is the queues that can form during busy periods due to the time it takes for even a fast charger to fully replenish a vehicle's batteries. The rising popularity of fast, high-current charging stations also serves to highlight the demand that will be placed on local electricity grid infrastructure to accommodate sufficient numbers of charging stations. Although electric truck adoption is still in its infancy, this will put yet more strain on supply infrastructure.

In this white paper we investigate how the increase of electric vehicle adoption will place demands on the power distribution infrastructure wherever charging might take place: in public parking lots, at the office or at home.

Articles about electric vehicles (EVs) usually start with impressive statistics about growth rates, and it's tempting to talk about projected EV sales; a figure from the organization IEA[1] is an example, predicting that the global stock of electric passenger vehicles will rise from 5 million in 2018 to around 250 million by 2030, with sales at about 44 million per year at that point. This is in the EV30@30 scenario, where 30% of all EVs (except two-wheelers) have a 30% global market share by 2030 (Figure 1). The figure includes cars, buses and trucks in hybrid and full electric versions. So, temptation not resisted – but there has to be a reality check: what are the error bars on this growth trajectory, and what are the assumptions and identified risks? Drill deeper, and some of the data on growth from different sources shows big variances. The sales figure quoted has embedded assumptions about changes in EV affordability, future technology improvements, oil prices, regulatory incentives and "dozens" more. It's also highly dependent on the uptake in China, which was 45% of the market in 2018 compared with 24% for Europe and 22% for the US. Another figure from the US Energy Information Administration (EIA) Annual Energy Outlook 2020[2] shows total battery vehicle sales of much less than one million vehicles in the year 2030 in the US – less than a tenth of the IEA prediction if the geographical percentage split stays the same. It predicts that gasoline-fueled vehicles will still dominate sales to 2050 and beyond. So, take your pick of these data.

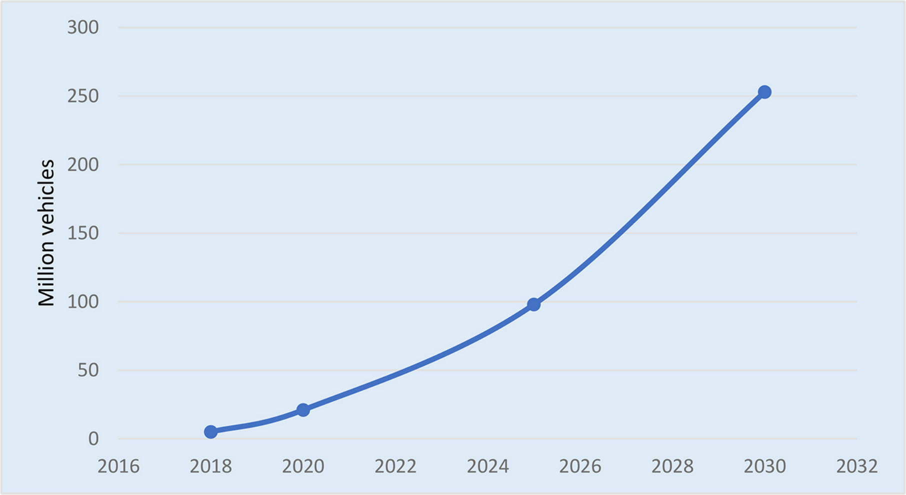

Figure 1: Projected global stock of all electric vehicles – 2018 to 2030. (Source: EIA)

EV Uptake Influencers

EVs are currently relatively expensive, so optimistic forecasts assume that prices will decrease with volume and technology improvements, but volume will only increase if prices drop. Chickens and eggs come to mind. Some manufacturers admit to losing money on each car sold, in efforts to stimulate the market, but that's not a great business model and it tests the patience of investors. Government pressure is another driver; with climate-change goals to achieve and pollution levels to control, administrations around the world have announced targets to ban the internal combustion engine (ICE) by certain dates. The headline impresses, but often they actually mean ban ICE-*only* vehicles, leaving hybrids in the mix indefinitely. Car manufacturers play with words in the same way, desperately trying not to "strand" their ICE manufacturing assets with promises of 100% electric lineups in their range at a future date when they actually mean 100% all-electric *or* hybrid.

Oil prices affect future EV uptake with their own pricing dynamics. While prices have been relatively stable recently, geopolitics have dramatic effects, as do any government subsidies. If the price per barrel of crude drops to less than $20 again (inflation adjusted) as it did in 1998, compared with today's figure of around $54, consumers might think again about EV running costs. Currently an EV gets about 43 miles for each electricity-dollar, about one-fourth of the cost of a gas-powered car or SUV.

The arguments for mitigating climate change and improving the environment might fade if the EV purchase and running costs don't provide an incentive to swap away from ICEs, even with the World Health Organization reporting 4.2 million premature deaths globally, linked to air pollution.[3]

Range Anxiety

A barrier to EV uptake is concern about charging. The original electric vehicles had a range of only 100 miles or so, making them a niche product for a particular type of driver who only ever made short trips, returning to base frequently for a "top up." Things have improved, with a range around 300 miles now for the better models, but anxiety still remains, with a conception that charging points are scarce. It's certainly a fact that a "stranded" EV out of juice can't just be revived with a spare battery from a passing Good Samaritan.

Compared with gas stations, charging "stations" might seem few and far between, but this is just supply and demand; in the US, there are about 270 million cars and 150,000 gas stations – with, say, 8 pumps giving about 225 autos per pump. Compare this with global figure of about five million EVs and around 410,000 public charging points, giving 12 EVs for each charging station – 18 times better availability! If you factor in office and home charging points, you have close to parity – one charging point for every EV.

Clearly the comparison can't be direct, though; a gas tank can be refilled in around ten minutes, maybe fifteen with a comfort break and a can of soda from the convenience store. However, recharging a battery could take hours from a "slow" charger at a highway service stop, so if all charging points are in use, and the next station is miles away, that availability figure isn't much comfort.

With everyone wanting to believe in the future of EVs, we can expect the infrastructure to be built to match one of the predicted uptake scenarios, hopefully the right one. There will be under- or over-shoot, though, with the uncertainty over demand and with local variables to take into account. You can be sure that Norway, where about 60% of new car sales are EVs, will have more charging points installed in the next few years than the UK, for example, where the figure was 1.6% for new EV registrations in 2019.[4]

Supply Anxiety

While range is something to get anxious about, should electricity supply in the future also be up there? At the moment, the load on the grid from EV charging hardly registers, and by 2050, according to Bloomberg ENF,[5] it will still only account for 9% of global demand, which has anyway grown 57% from 2018 figures. In the US, EV charging energy by 2050 is set to reach 800 to 900 terawatt-hours in a total consumption of about 30,000 terawatt-hours.

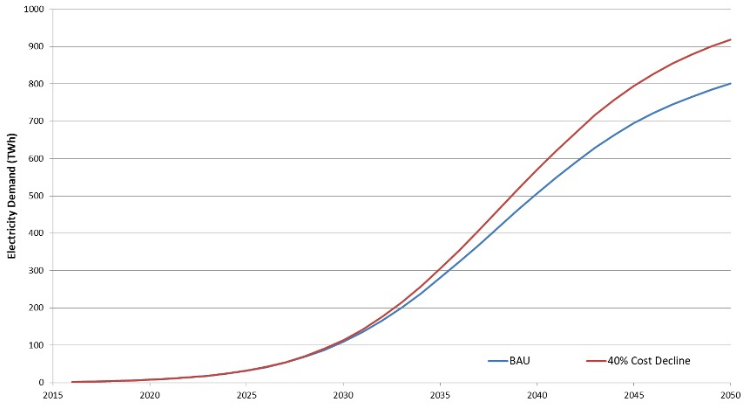

Figure 2: Annual electricity demand by electric LDVs in the US in the BAU scenario, and in a scenario with gradual cost declines reaching 40% of the BAU value in 2050. (Source: Energy Innovation)

Again, assumptions are made about technology improvements. For example, EVs are currently only about 59 to 62% efficient from battery energy to power at the wheels, so there is some expected improvement. (Compare this with ICEs, with just 17 to 21% conversion efficiency of the chemical energy in gas to motive power.) The figures quoted so far for EV sales and energy consumption relate only to light duty vehicles (LDVs). If electric trucks become a reality, the figures could be very conservative. The timescales associated with the build-out of charging stations needed and the upgrade of utility infrastructure extends way beyond government administration terms and immediate politics, but utility providers are anyway buying into the long-term inevitability of EVs and planning to have sufficient base energy supply. With infrastructure expansion for a growing general market anyway, the 9% of share for EV charging is not seen as problematic at the generation level. In distribution, however, as you get closer to the charging cable at the car, the situation is different.

Figure 3: High-voltage distribution will have capacity for EV charging.

Distribution Hardware for Future EV Charging Needs

Historically, electricity demand is low during the night, with load spiking at maybe 7am as toasters, electric showers and other domestic appliances kick in. It happens again in the early evening as cookers and heating/cooling work hardest. When adding home EV charging to the mix, the pattern changes dramatically, with load now peaking during the night so the car is ready to go for the morning commute. Standard home chargers might be 3 or 7kW, taking 6 to 12 hours to charge a full EV or 2 to 4 hours for a plugin hybrid electric vehicle (PHEV). This is “only” like running a high-powered heater or two all night, but “fast” chargers can be rated up to around 22 kW. This now approaches the limit of the incoming domestic supply, and is usually a higher peak level than without an EV and certainly a much higher average level throughout 24 hours. This is an immediate extra stress on the local distribution network as more homes get EVs, with the transformers on poles that drop the medium voltages down to domestic levels humming loudly in protest. The high-voltage distribution network and the power stations can cope better, as they are rated to supply industry as well, which peaks at a different time. Local supply infrastructure might therefore be the first bottleneck, with significant local variations – city apartments for example may have parking spaces, but the EV electricity supply won’t come directly from the end-consumer’s supply. It would be metered but aggregated at a higher utility level where the load is “leveled” across domestic and industry, and within the hardware ratings. The same is true of roadside and public fast-charging points where the load is more directly on the high-voltage network.

EV chargers are intelligent enough to control the rate of charging so the battery is ready at a programmed time with the required charge, but they don’t know about other demands on the supply. There is opportunity for “smart” chargers to interact with the utilities to stage the charging of EVs in a neighborhood to keep the total load within bounds. This not only helps prevent overloading, but is also a positive benefit to the utility companies, which appreciate a leveled load, thereby avoiding the expensive spinning up and shutting down of power plants from peaks and troughs of demand. In some areas the utilities encourage this with rebates and special rates for smart charging during off-peak hours.

In addition to implementing a host of smart features and connected infrastructure, there are the usual challenges associated with designing high-power charging and battery monitoring systems, both in the vehicle and for the charging infrastructure. Many of these are already well known to power systems design engineers, with energy efficiency, heat dissipation and power line conditioning being among the top three considerations. In an electrical environment where high-power load switching happens regularly, the supply can experience dramatic high-speed dv/dt transients. Such high-voltage spikes can cause catastrophic and permanent damage to connected equipment if it is not adequately protected. The use of specialist high-power protection devices such as the Bourns Hybrid GMOV is highly recommended for all types of EV infrastructure equipment. Comprising a space-saving gas discharge tube and a metal oxide varistor in a single compact, low-leakage and long-life package, it provides a very reliable method of protecting any electrical circuitry from overvoltage transient surges.

Win-Win with Renewables

A long-standing objection to EVs is that they aren't so "green" as they make out, if the electrical energy for charging ultimately comes from dirty coal or gas-fired generators. The situation is changing with increased use of renewables, but with the downside of unreliable supply without sun for solar at night and unpredictable wind for turbines. The ideal would be some means of energy storage to level supply capability, but there are no perfect solutions – hydroelectric storage in lakes only suits some topography, for example. While there are some promising ideas such as storage of compressed gas in bedrock, one possibility is to use the combined batteries of EVs to "lend" energy back to the grid as a buffer in return for a rebate on your bill (Figure 4).

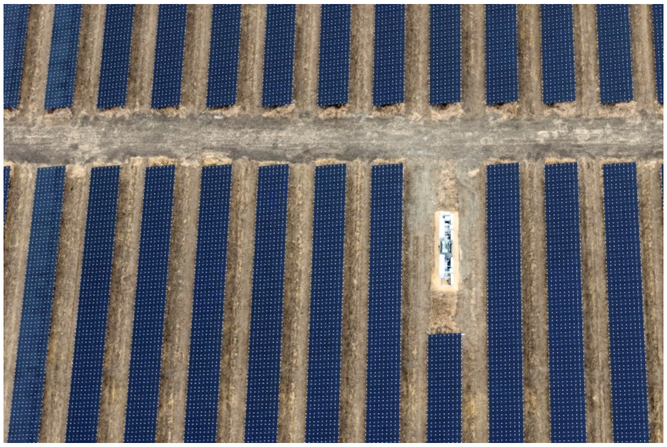

Figure 4: Solar energy can be stored in EV batteries.

Returning energy to the grid requires bi-directional chargers, but the technology is there. If you know your car is going to sit unused, the utility company could be draining and recharging the battery for its benefit without affecting you, as long as the smart charger is programmed to know when you need the car fully charged and ready to go.

[1] IEA (2019), "Global EV Outlook 2019," IEA, Paris https://www.iea.org/reports/global-ev-outlook-2019

[2] https://www.eia.gov/outlooks/aeo/

[3] https://www.who.int/airpollution/ambient/health-impacts/en/

[4] https://www.drivingelectric.com/news/678/electric-car-sales-uk-2019-stars-110-jump

[5] Bloomberg BNEF Blog: "Global Electricity Demand to Increase 57% by 2050"