UTILITY SERVICE AND BATTERY SIZING FOR STORAGE-BACKED EV FAST CHARGING STATIONS

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Overview

Since 2015, the number of electric vehicles in the US has increased by a factor of almost 20x, from under 400k in 2015 to about 7M in 2025; over the next decade, the fleet is expected to increase another 10x to more than 80M vehicles by the end of 2034 (BNEF 2024 EV report). This rapid increase in the electric vehicle fleet, combined with increasing utilization of public DC fast charging by the current fleet, is resulting in a massive expansion of demand for electric vehicle fast charging. In order to make efficient investments of capital into charging infrastructure and grid connection capacity, it is critical that charging stations are designed to serve the energy needs of the evolving fleet needs as efficiently as possible.

Charging station electrical loads have high variance and low load factors (large peak to average power ratios). Capital cost and utility impact can be optimized using load management and on-site storage, with minimal to no impact on the driver experience. This paper presents a methodology for efficiently sizing utility service for a charging station, considers the impact adding a battery to a charging station has on required service, and presents some quantitative conclusions on ideal grid and battery sizing for a charging station.

Summary of findings

Electric Era has established a set of standard station designs that offer an uncompromised charging experience while significantly reducing the power delivery infrastructure needs of the site. These stations can deliver high quality charging experiences at high utilization while more than halving peak demand on the grid, resulting in lower peak power draws and reduced upstream utility infrastructure. This reduces both the capital cost and lead time of station installation (which is often paced by long transformer lead times), and reduces the operational cost of running a station in utility districts with demand-based electricity tariffs. A summary of Electric Era's standard station designs, informed by the analysis laid out in this paper, is presented in Table 1. Section 06 and Table 5 address NEVI-specific station sizing considerations.

Table 1: Electric Era's standard station design points

200 kW Charger Count	**Nameplate DC Output** *(kW)*	**Service Size** *(A@480V 3ϕ)*	**Transformer Size** *(kVa)*	**Battery Power** *(kW)*	**Battery Energy** *(kWh)*	**Oversubscription Ratio** *(excl. battery)*
2	400	400A, 80% rated main	150 min 225 pref	125	220	2.7
4	800	400A, 100% rated main	300	233	220	2.7
6	1200	600A, 100% rated main	500	250	379	2.4

Grid and battery sizings scale to a first order with nameplate DC output, and to a second order with port count, assuming each port's power is close to fleet average peak power. Deviations from these standard design points can be considered on a site-by-site basis. The impact of those deviations can most simply be thought of as a reduction or increase in the maximum utilization a site can support. As a result of this, we weight towards undersizing versus these standard designs when designing sites with lower than average expected utilization.

What is oversubscription, and why does it make sense?

EV fast-charging is a particularly challenging use case for utility service sizing. EV charging curves tend to have a high peak to average power ratio, and the stochastic nature of EV fast charging makes peak power and utilization factor highly variable over time. By means of example, the Tesla Model Y and Model 3, the two best-selling EVs in the US that together make up more than half the currently driving US EV fleet, peak at 250kW of charging power, but over a charge from 10% to 90%, average less than 100 kW of power consumption [Source].

Figure 1: Model Y charging performance

The high peak to average power ratio of EVs compounds with time-variable station utilization for an even higher peak to average power ratio at the station level. Designing a station to supply the maximum possible instantaneous power results in a significant capital overinvestment that will rarely, if ever, be fully utilized. Realizing this, the many players in the charging industry utilize load management to design their grid connection and AC power conversion to a smaller power consumption than the sum of their rated DC vehicle output. The application of this concept allows operators to maximize capital efficiency of their sites and grid upgrades with minimal impact on charging performance.

This is evident in the design of Tesla's Supercharger stations, the largest DC fast-charging network in the US. Tela's V3 Supercharging stations (the bulk of their currently deployed charger fleet) can output a maximum power of 250kW at each port. Their smallest typically installed station consists of 2 power conversion cabinets and 8 ports. This 8-port station has a port capacity of 2000 kW in total, but Tesla typically installs no larger than a 750 kVa transformer for this size station and a matching amount of AC conversion. This nearly exactly matches 8x the average power of a Modely Y 10-90% charge. This ratio between the total DC nameplate charger capacity of the station to the installed AC input is henceforth referred to as oversubscription. The Tesla station has 2000 kW of DC charger capacity for 750kVA of grid connection, an oversubscription ratio of 2.7:1 .

As can be seen in the summary table, Electric Era targets a similar DC nameplate: grid connection oversubscription ratio, but utilizes a battery in addition to the grid to substantially increase driver charging performance in high utilization windows.

What are the drawbacks of oversubscription?

Oversubscription of DC output capacity to AC input means that, at high enough utilization, there are occasions where cars will receive a charging power below requested. This is referred to as an underservice event. While there are multiple strategies to safely handling underservice events from a load management and electrical infrastructure safety perspective, if they occur frequently enough, they can have a significant negative impact on user experience and degrade the total energy that a station can output, the primary source of revenue for most paid DC fast charging stations. There are two actions that a site designer can do to mitigate these possible drawbacks:

1. Design charging station with an oversubscription low enough that underservice events impact only a small fraction of stations total users
2. Add other power sources at the station (typically stationary battery storage) to supplement peak power from the grid, decreasing the probability of an underservice event

While straightforward in concept, turning these actions into quantifiable metrics and applying them to the design of actual stations is a complex undertaking.

How does Electric Era size stations?

Electric Era takes a 3 step approach to sizing the grid connection and battery capacity at our stations.

1. Determine the number of charging ports at a site and the DC output of those ports
2. Assess the instantaneous power needed to keep underservice events to an acceptable likelihood at a design utilization target
3. Determine how to split the instantaneous power into the fraction supplied by the grid and the fraction supplied by the battery, and verify battery energy storage capacity is sufficient for design target utilization.

Step 1: Determining port count and output

Port count is determined on a site by site basis. Considerations include space constraints at the site, expected utilization & utilization growth of EV charging in the area, customer desire and budget, and funding program eligibility requirements. The peak utilization that a station can support scales linearly with the number of installed chargers, so this is an important consideration in the overall economics and power consumption of the station.

Max per-port power is decided in equipment selection. Electric Era works with a small number of charging station hardware providers, and selects between them based on customer feedback, funding eligibility requirements, and availability. Electric Era offers standard station sizing at 2, 4, and 6 chargers, and can expand beyond that if needed. Our standard chargers are capable of delivering 200kW individually, or 100kW when adjacent ports are in use. Stations can be customized to meet the needs of the individual use case.

Step 2: Determining required instantaneous power

Electric Era employs a utilization based charging station model to draw quantitative conclusions about the sizing of the grid connection. The critical inputs to this model are vehicle temporal distribution [EVSession data], fleet composition [Kelly Blue Book EV sales], vehicle charging curves, vehicle energy request distribution [Electrify America Annual Reports: National, California], port count, and max port power.

This model is first used to establish the instantaneous output power of the system. Thousands of sessions at different station utilizations are run, and total power requested from the carflow is captured and aggregated into a set of cumulative distribution functions (CDF) of station charging power at different utilizations.

As utilization increases, the utilization CDF curves begin to clump together - this is indicative of the charging station saturating. Designing a station for operation at full saturation should be avoided, as this would result in long queues and drivers leaving for other stations. Industry guidance on maximum design utilization varies. Electric Era considers 50% utilization to be the maximum practical design utilization for a given site. For comparison, in 2023, Electrify America's average utilization across their US fleet of charging stations was 16%.

Electric Era designs our stations to meet the instantaneous demand of the charging vehicles for more than 95% of sessions without capping or limiting vehicle power. For a 4 charger station, the analysis above indicates that 100% saturation occurs at 250 sessions per day, and 50% utilization occurs at 125 sessions. This scales linearly with charger count. We use the cumulative power distribution functions mentioned above to determine the minimum instantaneous station power needed to meet this 95% design criteria, which is subsequently referred to as the **Peak Design Power**.

At absolute minimum, the grid connection must be able to supply the average power consumption of a given utilization profile for the energy balance to close, regardless of the storage capacity at the site. This sets a lower bound on our initial service sizing considerations, and is determined by looking at the mean value of the CDF curves at our target design utilization. The results of this analysis are summarized in Figure 2 & Table 2.

Figure 2: Power probability distributions for different utilizations at different charger count

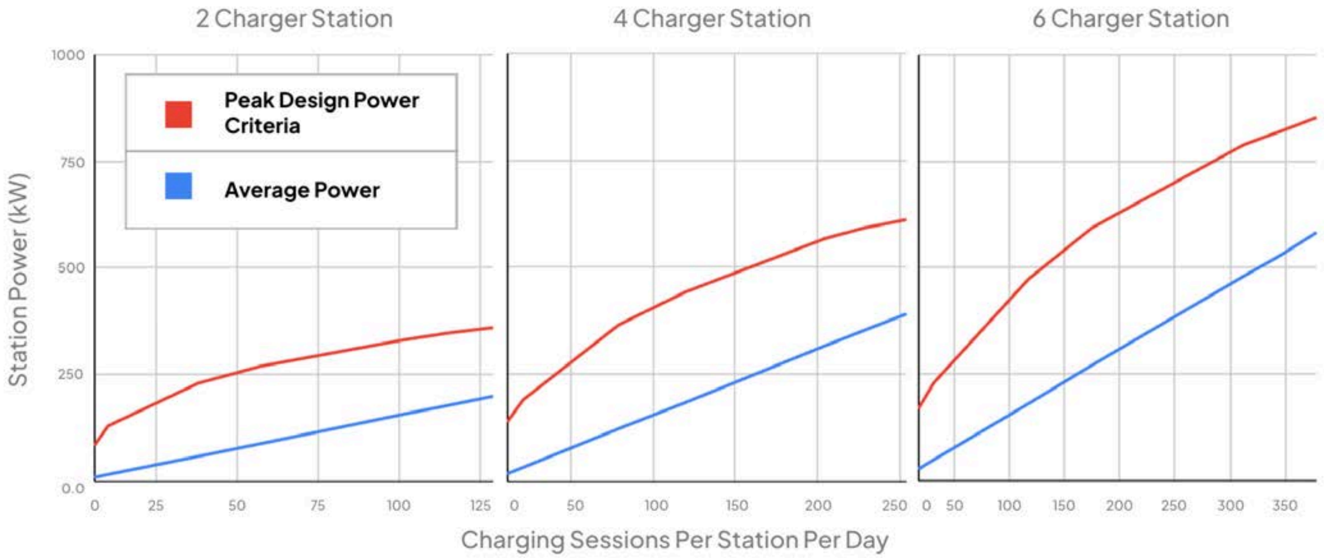


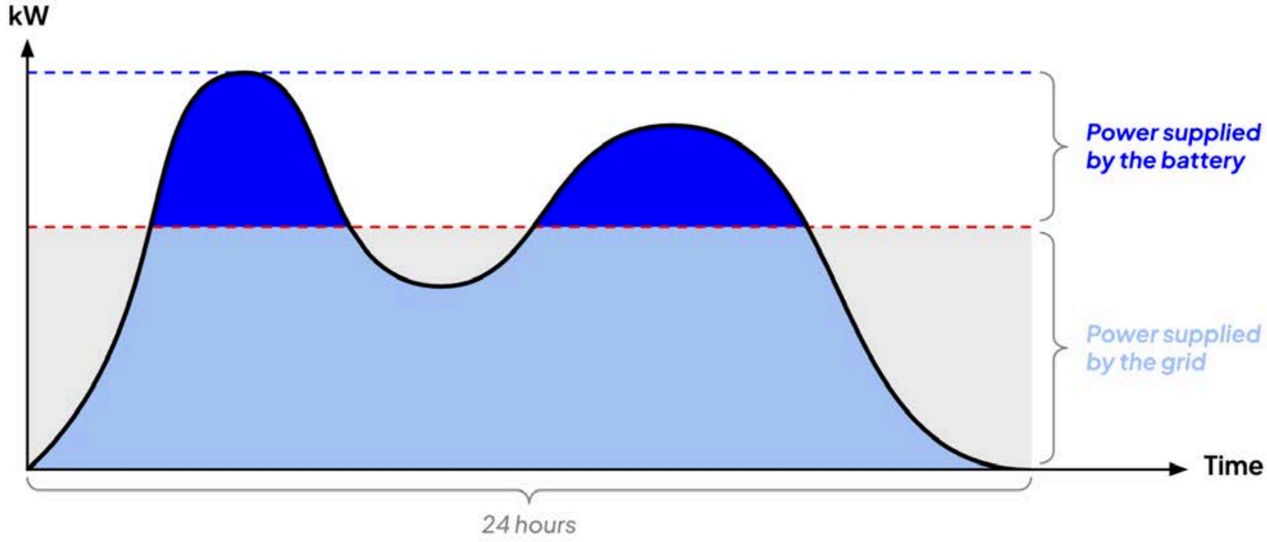
Table 2: Design utilizations by charger count, with instantaneous power design requirement and minimum theoretical grid connections at design utilizations

Charger Count	**Saturation Session Count** *(Sessions / Day)*	**50% Utilization** *(Sessions/ Day)*	**Peak Design Power, 50% Utilization** *(kW)*	**Min Theoretical Grid Power Required** *(kW)*
2	129	65	279	99
4	250	125	450	193
6	378	189	613	292

Step 3: Determining service and battery sizing

At Electric Era charging stations, power is supplied to charging cars from a combination of the grid connection and one of these battery energy storage systems. In order for the site to meet our design requirements, the battery and grid must be able to meet or exceed the 95% peak power criteria established in step 2, and the battery must have enough energy capacity to not run out of energy during the course of a day at our design utilization. Figure 3 shows a simplified cartoon of power and energy flows at a station to help develop understanding of the process.

Figure 3: Demonstrative sketch of battery-backed charging station behavior



The black line is the instantaneous power sent to the EVs. The red dashed line represents a selected grid connection size that is less than the peak EV demand, and the blue dashed line is the peak instantaneous power sourced from the grid and battery combined.

The area under the black curve is the total energy dispensed to the EVs. The area in dark blue represents energy that must be sourced from the battery. The area in gray represents the energy available from the grid to recharge that battery. For the day-to-day energy balance of a charging station to close, the area in gray must be larger than the area in dark blue. Increasing grid connection decreases the energy required to be supplied from the battery (the area in dark blue) and increases available energy to recharge it (the area in gray), allowing for a smaller battery.

Electric Era currently offers 3 different standard battery configurations, shown in Table 3:

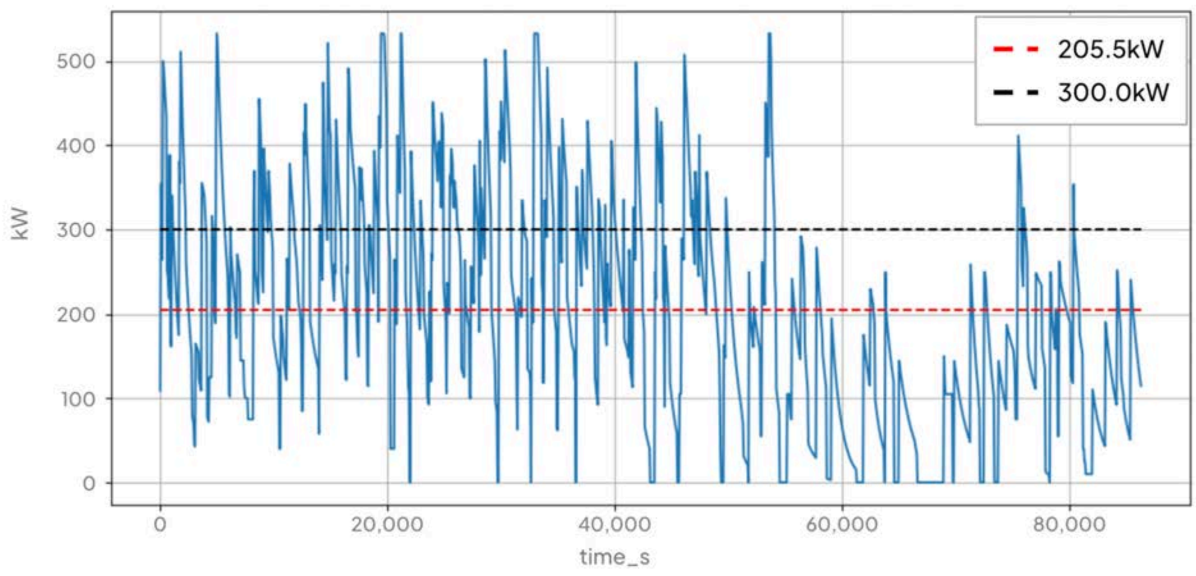
Table 3: Electric Era's standard BESS offerings

	Power Output *(kW)*	**Energy** *(kWh)*
Configuration 1	125	220
Configuration 2	233	220
Configuration 3	250	379

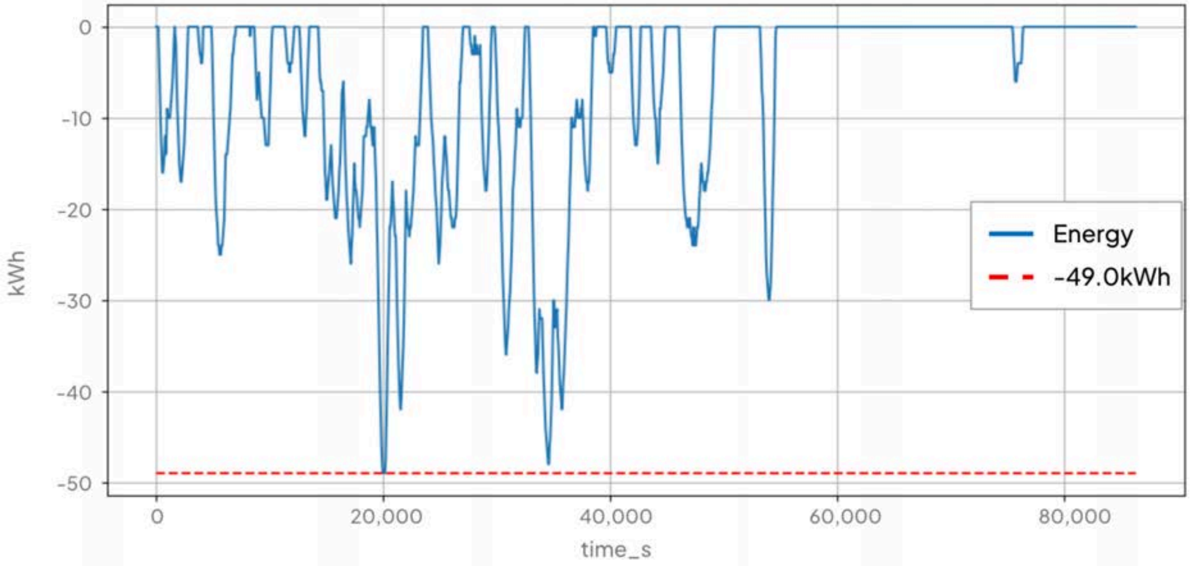
Electric Era first selects a grid and battery sizing to achieve the peak power requirement. We use the smallest standard transformer & service sizing that we can support with the power output from one of our standard battery systems.

Next, we confirm that the energy in the selected system is sufficient and will not run out of power during operation at our target design. This is done by simulating a year of design-target utilization charging with the selected service and battery size, using the utilization-based charging model introduced in Step 2. Figure 4 shows a single day of that charging simulation, pulling out instantaneous station power in the top chart, and tracks battery energy in the bottom chart.

Figure 4: Peak station power over a single day of charging



Battery energy over a single day of charging



Two critical battery energy metrics are tracked over the full year of simulated charging: maximum daily battery depth of discharge, and average energy throughput.

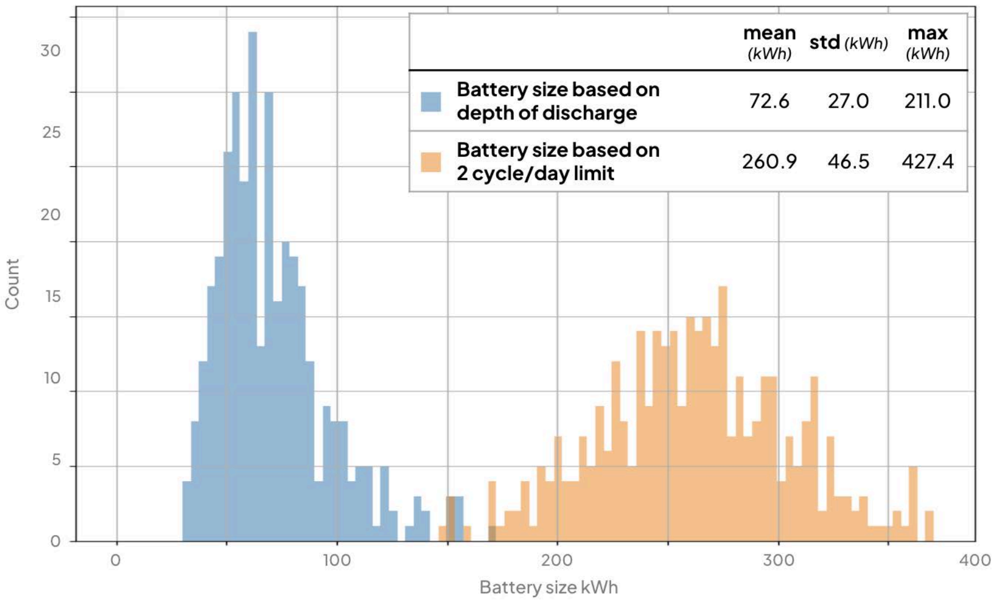
Maximum daily battery depth of discharge is the deepest discharge the battery sees over the course of the day. This number must be smaller than the storage capacity of the battery in order for the battery to not run out of energy. Because the impact of the battery running out of energy is significant for driver experience, we verify the energy in the selected battery configuration is larger than the 3-sigma single discharge event probability.

Average energy throughput is the total energy discharged by the battery over the course of the day. For this application in particular, as can be seen in the single day charging curve above, many smaller charge/discharge cycles are happening over the course of the day. Lithium Ion batteries have both cyclic and calendar-based aging mechanisms. Electric Era uses a Lithium Iron Phosphate chemistry in our packs, specifically chosen for its high cycle life performance. In order to guarantee the batteries are able to meet and exceed our standard warranty terms, the batteries should average less than 2 cycles per day over their life. Since every day of a station's expected life is not expected to occur close to the design target utilization, this criteria is more flexible than the maximum discharge criteria and is considered against the mean.

Figure 5 shows the distribution of maximum daily battery depth of discharge, and the battery size needed for average energy throughput to be limited to 2 equivalent cycles over the full year simulation for a 4 charger, 300 kVA grid connected station with a 233kW battery.

Figure 5: Histogram of Daily Battery Energy Metrics
Over a Simulated Year of Charging at the Design Utilization Target

Grid connection 300kVA, average 125 sessions per day



	mean *(kWh)*	**std** *(kWh)*	**max** *(kWh)*
🟦 **Battery size based on depth of discharge**	72.6	27.0	211.0
🟧 **Battery size based on 2 cycle/day limit**	260.9	46.5	427.4

This analysis is performed at every grid / battery sizing combination, and the results are shown in Table 4 for Electric Era's standard station configurations. As can be seen, the energy capacity of the batteries is always larger than the 3 sigma single discharge events, and close to the 2 cycle per day throughput sizing, indicating the system can spend most of its life operating at its design utilization target without unexpectedly quick degradation of the battery.

Table 4: Summary of power and energy analysis showing the selected standard design points.

Charger Count | Nameplate DC Output (kW)	2 | 400	4 | 800	6 | 1200
50% Utilization Target (SPD)	65	125	189
Peak Design Power at Design Utilization (kW)	279	450	613
Min Grid Input (inc. efficiency/PF) (kW)	175	250	408
Selected System Battery Power (kW)	125	233	250
Standard Transformer Sizing (kVA)	150	300	500
3-Sigma Single Discharge Energy (kWh)	123	158	92
2 Cycle Per Day Throughput Sizing (kWh)	228	261	169
Selected System Battery Energy (kWh)	220	220	379