Energy Storage Paired with Electric Vehicle DC Fast Charging

Demonstration and Analysis in Hawaii

3002012710

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Technical Update, March 2018

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ABSTRACT

This interim report documents initial findings based on 2017 data collected from a project pairing stationary energy storage with a DC fast charger (DCFC) at Kapolei Commons, a shopping, dining, and entertainment center in West O'ahu. The primary purpose of this stationary energy storage system is to reduce peak power drawn from the grid with as little impact to customer electric vehicle (EV) charging times as possible. This report examines the efficacy of stationary storage in combination with a DCFC at achieving HECO goals and meeting customer charging needs. The report also provides an overview of the state of the stationary energy storage system. The following key topics are addressed:

- Assess grid impact/benefit
- Evaluate customer impact/benefit
- Assess performance, durability, cycling dispatch
- Determine usage and grid impacts
- Quantify application benefits and validate methods using analytics benefit tools
- Examine deployment and operation experience

Keywords
Stationary energy storage
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Electric vehicle (EV)
Grid impacts

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PRIMARY AUDIENCE: Utilities, especially Hawaiian Electric Company (HECO)

KEY RESEARCH QUESTION

How does the inclusion of stationary energy storage with a DC fast charger (DCFC) impact the grid and the customer electric vehicle (EV) charging experience?

RESEARCH OVERVIEW

Three types of data from the installed charging system—1-minute power quality (PQ) monitoring data, 1-second battery management system (BMS) data, and charging event data—were collected for the months of November 2017 and December 2017. This data was cleaned, processed, and visualized to clarify how much customer time was lost/saved as a result of an imposed 23-kW limit on power from the grid and the inclusion of stationary energy storage. Additionally, the effectiveness of the overall DCFC system for meeting the maximum grid power requirement was assessed.

KEY FINDINGS

- Over the two-month period, the addition of stationary storage allowed the DCFC to deliver power to customer EVs at a higher rate than would normally be allowed by the distribution infrastructure, reducing the total customer charging time by an estimated 21.8 hours.
- The average power delivered to vehicles at the test site was still 77% of that of comparable chargers nearby.
- Reduction of charging time in the future will depend on whether the energy capacity of stationary storage is sized to meet future increases in EV energy capacity.

WHY THIS MATTERS

The impact to the grid from a growing EV market combined with higher charging power and greater vehicle energy storage capacity will need to be addressed. DC fast charging demand involves a load with very tall, thin peaks and a very low load factor. This demand could be met by the traditional distribution power capacity infrastructure, but the shape of the load lends itself well to stationary energy storage. The demonstration described in this report is a real-world exploration of the benefits and potential pitfalls of the stationary storage approach. While it is impossible to perfectly predict the future, the results of this study speak to the value of energy storage to hedge against future growth in charging power/energy and the risk of installing an undersized storage system.

HOW TO APPLY RESULTS

This short interim report may be used by a utility or product designer interested in creating/installing stationary energy storage with EV chargers to reduce peak load while minimizing impact on customer charge times. The lessons learned here could be valuable for sizing a stationary storage system, understanding its use, or valuing this type of application.

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PROGRAM: P94: Energy Storage and Distributed Generation

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STATIONARY ENERGY STORAGE PAIRED WITH DC FAST CHARGING

This interim report will serve to report initial findings based on the data collected in 2017 from the stationary storage paired with DC fast charger (DCFC) project at Kapolei Commons, HI. The primary purpose of the stationary storage is to reduce the peak power drawn from the grid with as little impact to customer charging times as possible. This interim report examines the efficacy of the stationary storage at achieving its goals and provides an overview of the state of the stationary storage. The research questions to be answered in this report are outlined below.

- Assess Grid Impact/benefit
- Assess Customer impact/benefit
- Assess performance, durability, cycling dispatch
- Assess DC fast charging usage and grid impacts
- Quantify application benefits and validate benefit methods using analytics benefit tools
- Assess deployment and operation experience

The data presented below represents three distinct data streams. There is 1-minute AC power data taken from the PQ monitor which represents the net power drawn from the grid by the DCFC and stationary storage. The battery management system (BMS) provides 1-second power information to/from the stationary storage and the vehicle. Finally, charging event data, including a timestamp, duration, and total energy transferred to the vehicle is also collected. For comparison and context, usage data from two similar, nearby chargers (Ward Ave 1 &2) are occasionally presented.

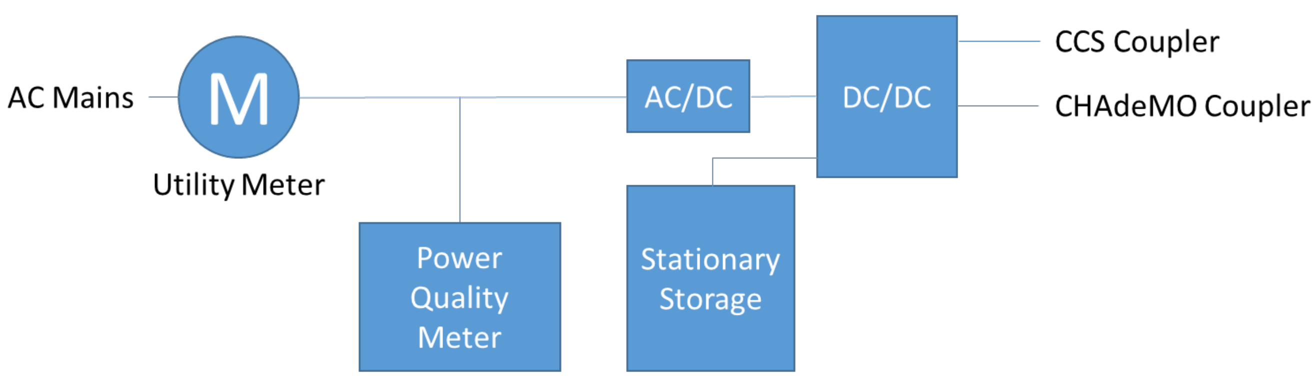

Figure 1-1
System Block Diagram

Power vs Time Profile

The effect of the stationary storage can be seen on a representative sample of the facility's power profile below. Before the stationary storage, the vehicle charger would draw a peak load of >40kW from the grid during this time period but because of the stationary storage's discharger, the peak load is limited to 25.35 kW. The 1-second BMS data is aggregated into 1-minute intervals for combination with the 1-minute PQ monitor data.

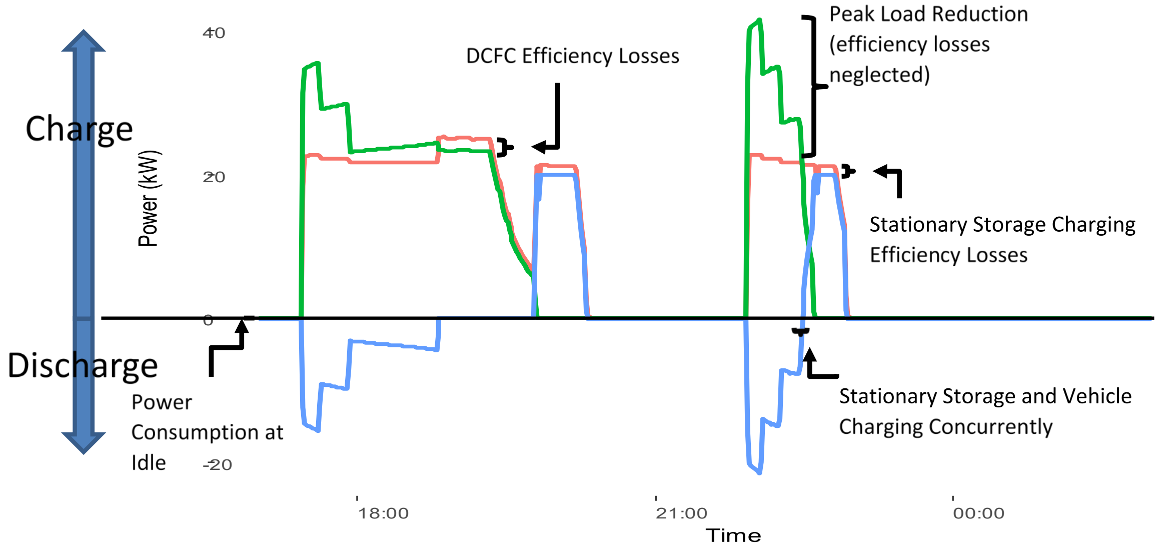

Figure 1-2
Representative Data Sample

The sign convention for the plot above is positive means power flow away from the grid, negative means power flow towards the grid. This contradicts the usual stationary storage sign convention because in this case, negative power means the stationary storage is discharging. This shows up in the state of charge of the stationary storage, shown below.

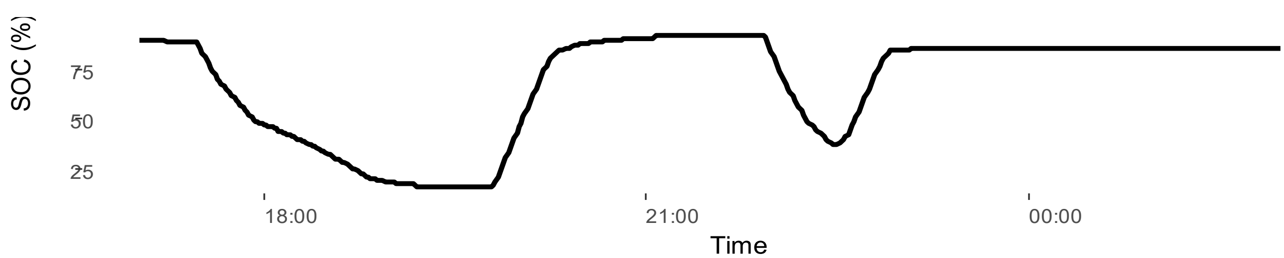

Figure 1-3
Stationary Storage State of Charge (SOC)

The data in Figure 1-4 represents the charging patterns for all three vehicle chargers for the 176 days between 08/17 and 12/2017. The chargers are used the most between 7am and. There are charging reports available for the Kapolei Commons charger for 119 of those days. On an average day, the Kapolei Commons charger is used 2.62 times, delivering an average of 22.88 kWh per charge (see Figure 1-4).

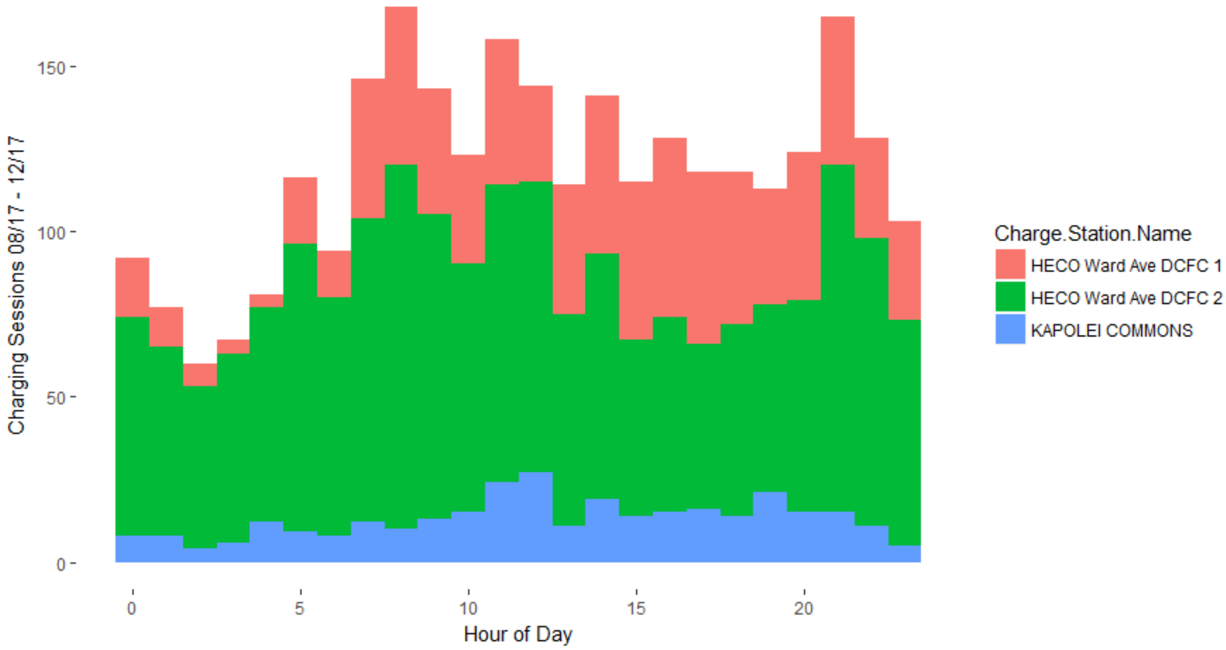

Figure 1-4
Charging Patterns for Kapolei Commons and Ward Ave. 1&2.

All of the chargers deliver a similar amount of energy per charging session.

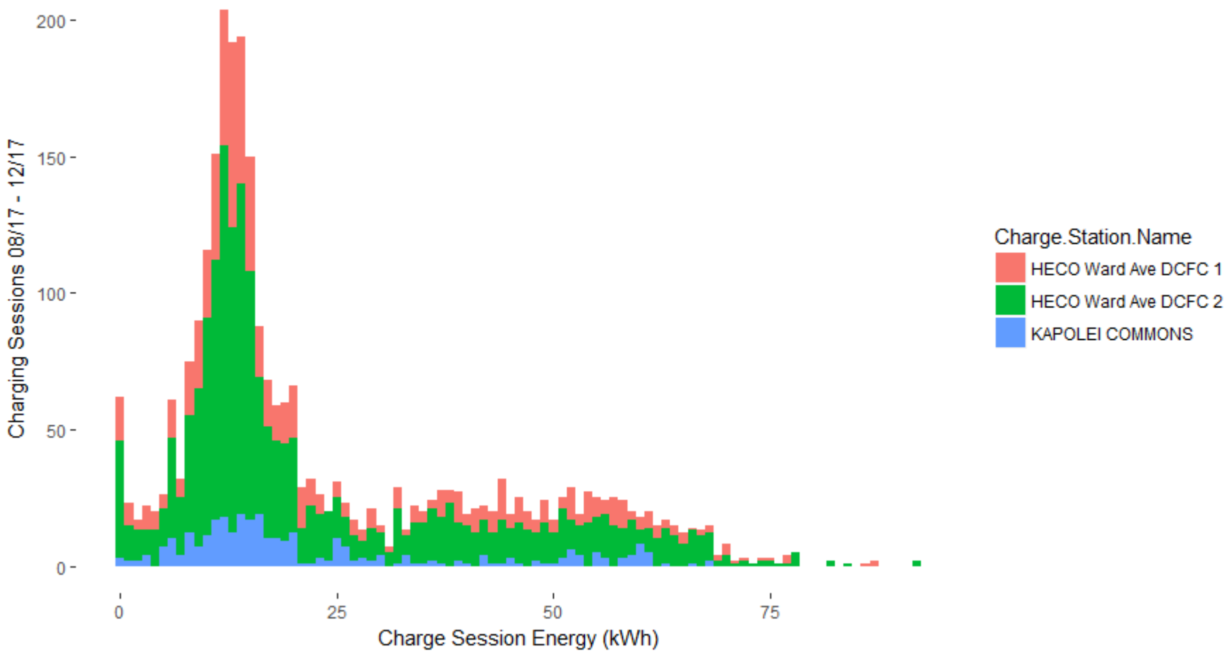

Figure 1-5
Vehicle Charge Energy per Session

The average charging energy for one session is 22.88 kWh. The stationary storage was designed with small electric vehicles in mind, like Nissan Leafs, with on-board energy capacities around 24 kWh. However, vehicles with larger batteries have become more prevalent and so charging sessions consuming as much as 70 kWh are relatively common. These charging sessions are much more likely to deplete the stationary energy storage, causing the vehicle to charge solely from the grid at 23 kW. The effect of this on customer charging times is discussed in the customer impacts section below.

Power Consumption at Idle

When both the stationary battery and the fast charger are idle (consuming and producing approximately zero power), the average power draw recorded by the PQ meter is 58.3 Watts.

Efficiency

This section requires the note that there is an offset in the battery power data of -80W. In other words, when there are no power flows anywhere else in the system, the battery reports it is discharging at about 80W while not losing state of charge. Without correction, this indicates an efficiency greater than 1, which is impossible unless there is another source of energy. The vehicle charging power does not have any offset like this. The following efficiency calculations control for the 80W battery power offset.

The overall efficiency of the DCFC system is 88.01%. This is the total energy delivered to cars through the Kapolei Commons DC fast charger divided by the total energy passed through the PQ monitor. Note that this does not include any onboard conversion or charging efficiency losses within the vehicles. This can be broken out into a roundtrip efficiency of the stationary storage and an efficiency of the DC fast charger. To make sense of these efficiencies, it is important to note that not all of the energy delivered to vehicles goes through the stationary storage. Of the 4037 kWh delivered to vehicles through the DC fast charger, only 838 kWh were discharged by the stationary storage. A stationary storage roundtrip efficiency (DC-DC) of roughly 90% applies to this energy. Note that because the data comes from different sources, not all data can be directly compared. The numbers in the figure below come from the log files at > 1/second sampling frequency. The PQ monitor doesn't report this frequently, so the higher-frequency data has to be merged into this, resulting in some loss of data.

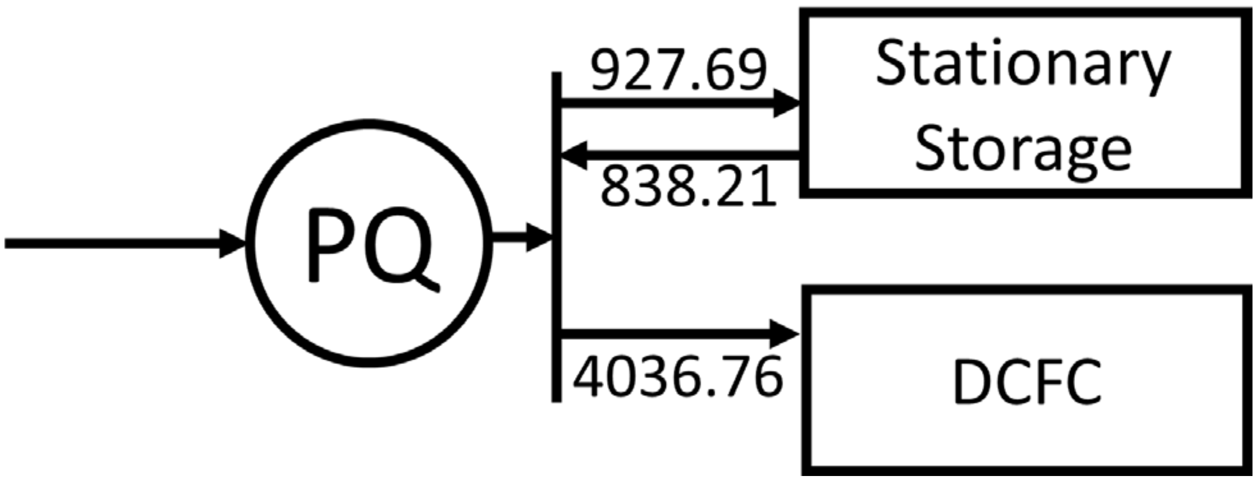

Figure 1-6
System Energy Flows (kWh)

Degradation

As with any similar battery energy storage system, this stationary storage is expected to degrade over time and with use. Ideally, a full discharge (100% SOC to 0% SOC) at rated power would be conducted periodically to estimate the remaining useful energy capacity of the storage system. This would interrupt the operation of the DCFC and would cause more degradation itself. Instead, we estimate the remaining useful energy capacity of the storage system using operational data by leveraging the internal SOC calculation.

To do this, we relate how much energy the battery cumulatively discharged in November and December, 2017 to the corresponding cumulative drops in SOC. In November and December, the storage system discharged a cumulative 852.8 kWh of energy. These discharges correspond to drops in the SOC of the battery equal to 7100%. In other words, 71 equivalent full discharges of the battery produced 852.8 kWh. This means that one full discharge should provide 852.8/71 = 12.0 kWh, which is the rated energy capacity of the storage system. However, the minimum SOC typically seen in the battery is 16% and the maximum is 95% (although the battery often stops charging between 80-95% SOC). This means that 95%-16% = 79% of the energy capacity of the storage system is being used regularly, representing **9.48 kWh**.

Another method is to identify a time when the battery is continuously discharged from a high SOC to a low SOC to mimic the preferred remaining useful energy capacity test. One event like this happened on 2017-10-20 and is shown below.

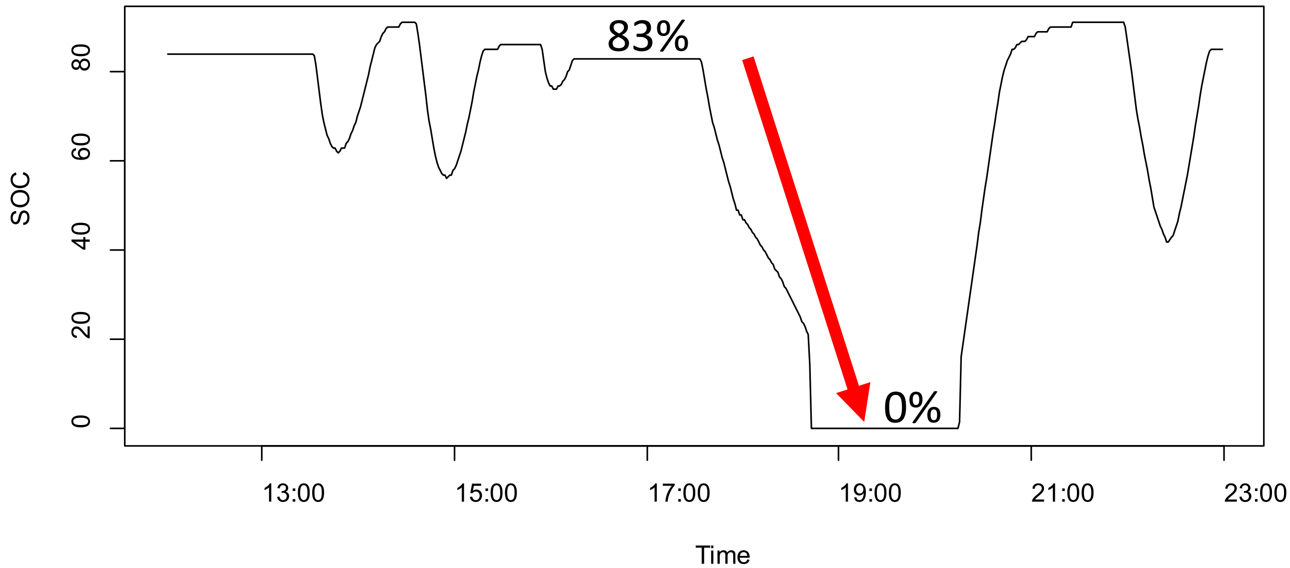

Figure 1-7
Large Stationary Storage Discharge Event

During this time, the stationary storage discharged continuously from a SOC of 83% to a SOC of 0% between 5pm and 7pm. This discharge resulted in a cumulative 7.863 kWh of energy being discharged from the stationary storage. However, it appears that no energy was transferred when the SOC dropped from 16% to 0%. So, this discharge represents only 67% of the energy storage capacity. Assuming the SOC calculation is correct, this means that a full discharge will contain **11.74** kWh of energy, similar to what was observed in the previous test. Regardless of how much the cells have actually degraded, it appears that roughly 9.5 kWh of useful energy capacity remain and only slightly less than the rated energy capacity assuming a full discharge.

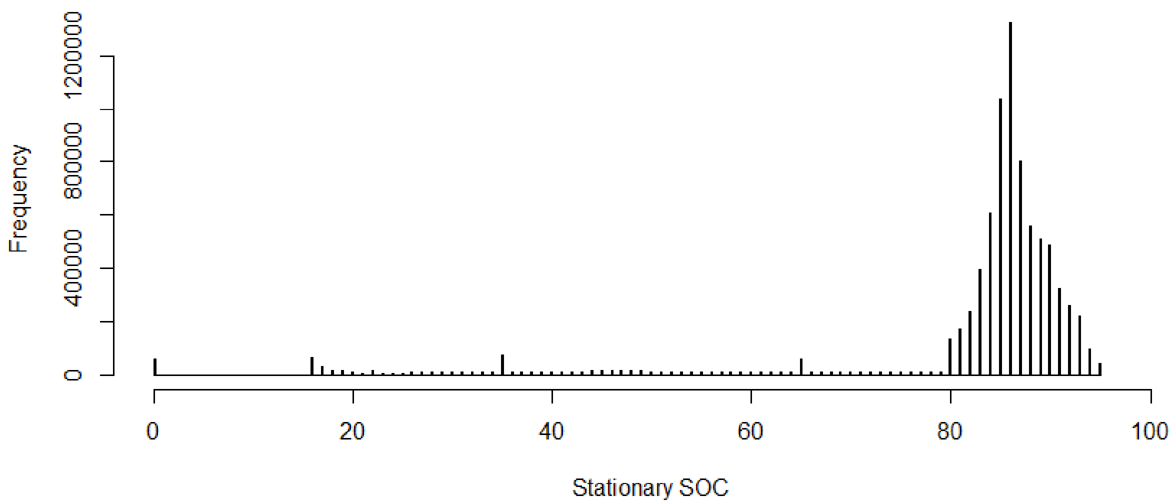

Figure 1-8
Histogram of Stationary Storage SOC

Simultaneous DC fast charging and stationary storage charging

The system can deliver power to a vehicle when the stationary storage is charging as well. The stationary storage will begin to recharge after a vehicle's charging power drops below 23 kW. The stationary limits its charging power to keep the total grid power beneath the 23 kW threshold.

Utility Impacts

Energy Cost Management

At the moment, the stationary storage is kept at a high state of charge when inactive (max=95%) and responds only to vehicle charging sessions. It is not generating any benefit from energy time shift and, due to the efficiency losses from charging and discharging, the stationary ESS will actually increase energy costs.

Peak Load Reduction

The stationary storage reduces the overall 1-second peak load from the DCFC by 19.55 kW. However, the PQ meter reads 1-minute average power values above the 23kW setting and above the 25kW grid limit. This is under investigation currently.

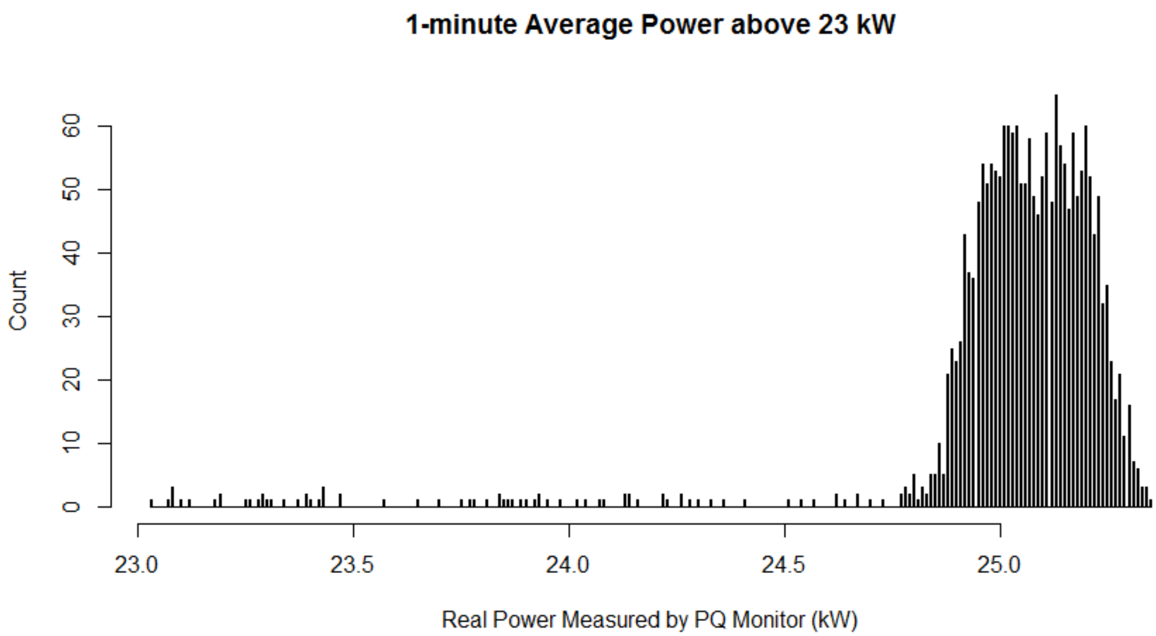

Figure 1-9
PQ Meter AC Power Readings above 23 kW

Customer Impacts

Vehicles cannot charge as quickly at a high state of charge and the longer a vehicle charges, the more likely it is to achieve a high state of charge. The time it takes a vehicle to charge to a high state of charge depends on its energy capacity and its state of charge at the beginning of the charging session. The plot below shows the charging duration on the x-axis and the energy delivered in the charging session on the y-axis for the two Ward Ave chargers, neither with a grid power limit or stationary storage. There is a reference line at an average of 25 kW over the charging session. A well-utilized charger would have charging sessions with high average powers (well above the red line). In general, we see charging sessions are clustered toward the 40kW line for long-duration charging sessions, although the average power per session drops off at very high charging durations. For short charging sessions, the average charging power is very broadly distributed between 10 kW and 40kW, representing a mix of vehicle types and beginning SOCs.

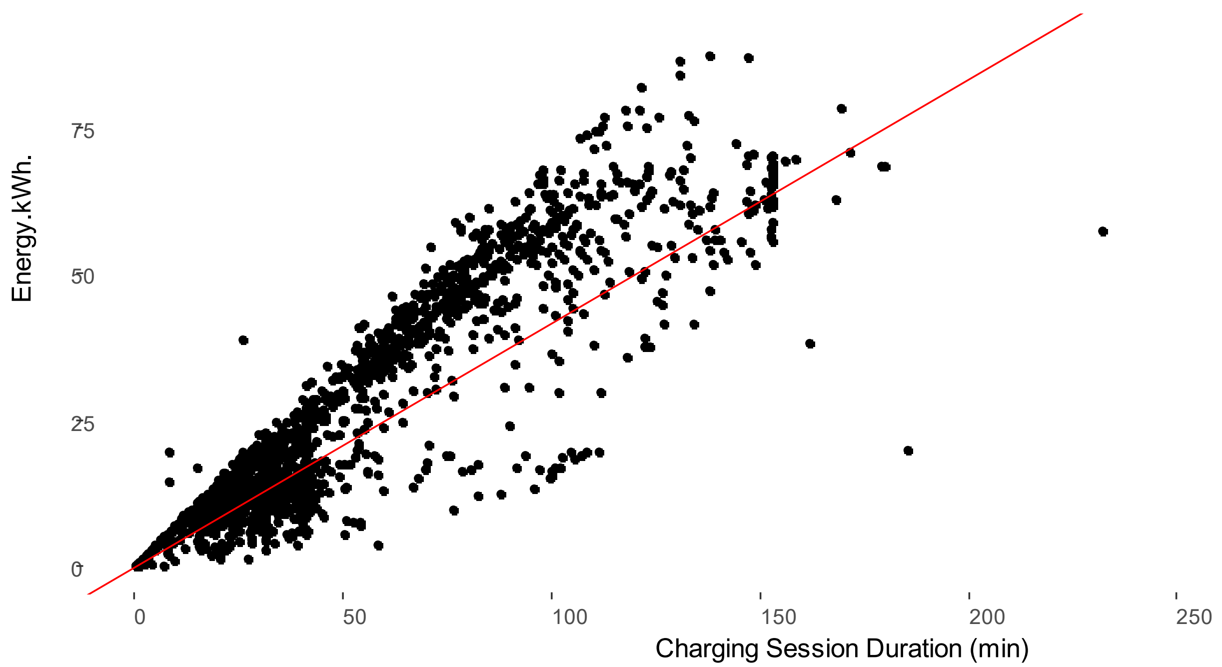

Figure 1-10
Ward Ave. Charging Sessions for Context

For the Kapolei Commons charger with stationary storage, the average charging power is much closer to 23 kW – the grid power limit. Whenever the storage cannot discharge to increase vehicle charging power due to not enough stored energy or any other reason, the charging power is 23 kW maximum (the limit set on the grid power). This impacts the average charge time. The average charging time at the Kapolei Commons charger is 61 minutes for a total energy of 22.9 kWh whereas the average charging time at the Ward Ave chargers is 50 minutes for 24.4 kWh. So, the average vehicle charging power at the Kapolei Commons charger is only 77% of the average charging power at the Ward Ave chargers.

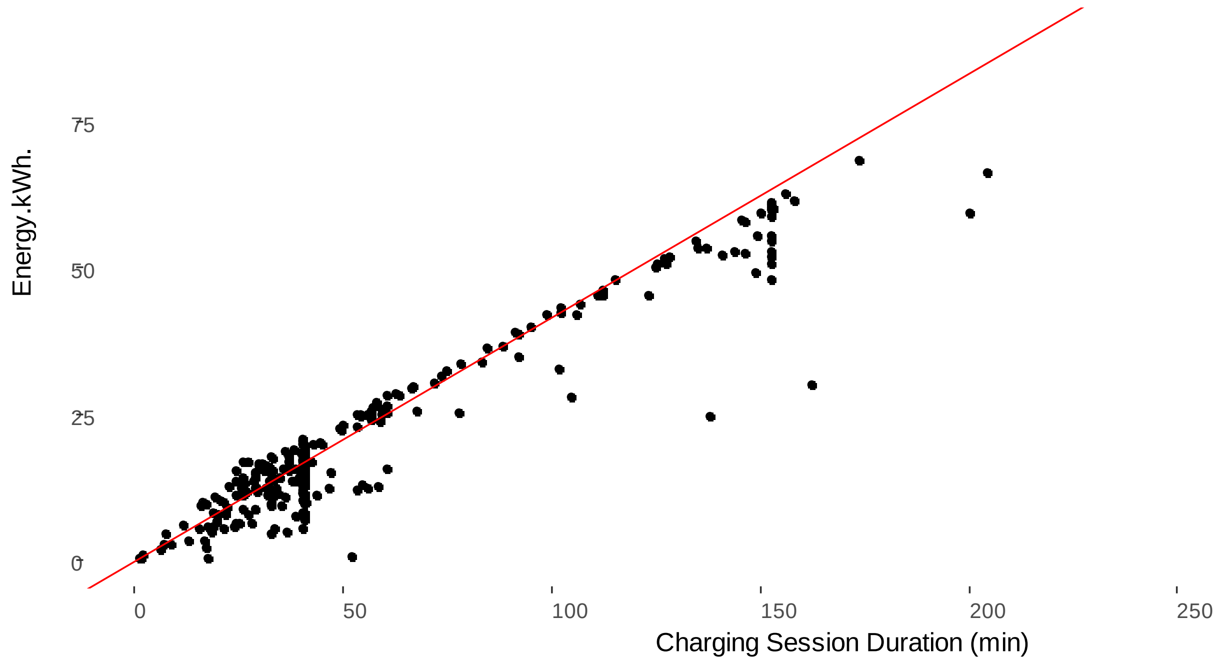

Figure 1-11
Kapolei Commons Charging Sessions

The rated energy capacity of the storage system when it was installed was 12 kWh. Higher-energy charging sessions, like can be expected from Tesla brand cars with large on-board energy capacities, are likely to deplete the stationary energy storage. When this happens, the charging power will be limited to 23 kW from the grid. Additionally, as the vehicles reach high states of charge, they will limit their charging power to avoid damaging their batteries. These effects combine and make the average charging power for long-duration sessions low.

To further explore the effect of this setup on the customers' charging times, two numbers are considered. The first is the number of customer minutes lost due to the grid power limit. When the storage system is depleted, it cannot discharge any more to speed up the customers' charges but the grid power limit is still in place. The second number is the number of customer minutes saved by the storage assuming the grid power limit is necessary.

Customer Time Lost to Grid Power Limit

The base case for this comparison will be a normal 50kW charger. To determine when a lack of energy in the stationary storage is limiting a customer's charging power, we look for vehicle charging power of 23 kW when the SOC of the stationary storage is low. There are many times when the vehicle is charging at the maximum grid power and the stationary battery is not charging or discharging (see below).

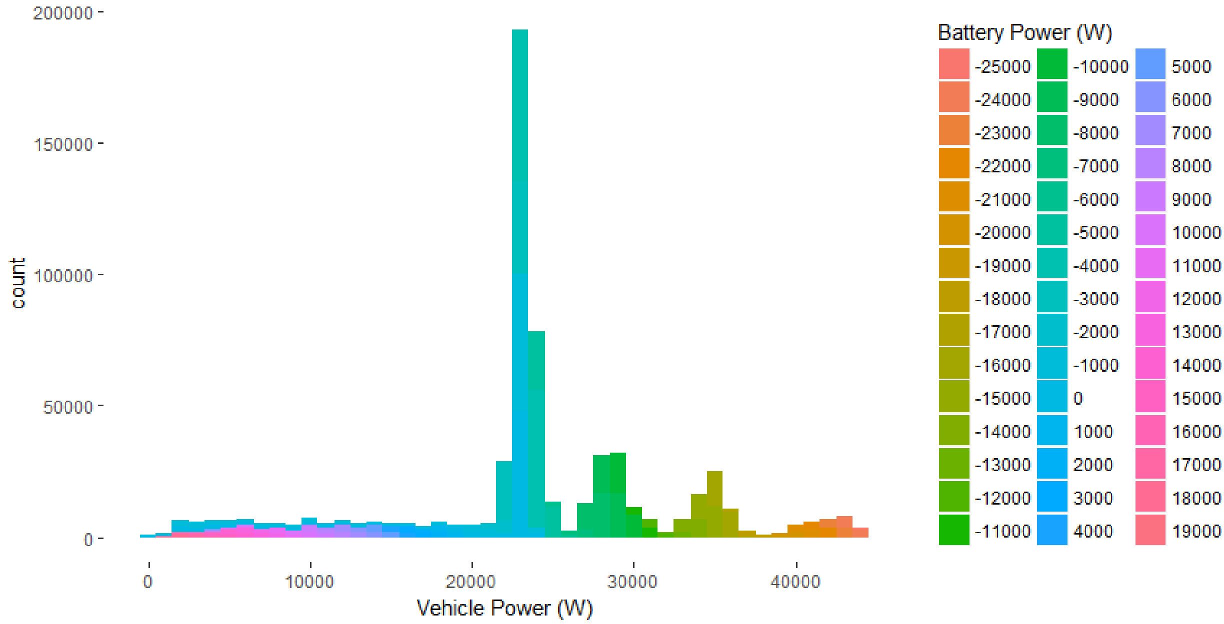

Figure 1-12
Histogram of Nonzero Vehicle Charging Power Colored by Stationary Storage Power

During these times, the SOC of the stationary storage is usually about 16% and the storage rarely discharges below 16%. This means the effective minimum SOC of the stationary storage is 16% and that the vehicle charging power is reduced to 23 kW when 16% is reached. As the plot below shows, this SOC minimum limits vehicle charging power for a considerable amount of time, reducing the average charging power to 77% of similar, nearby chargers.

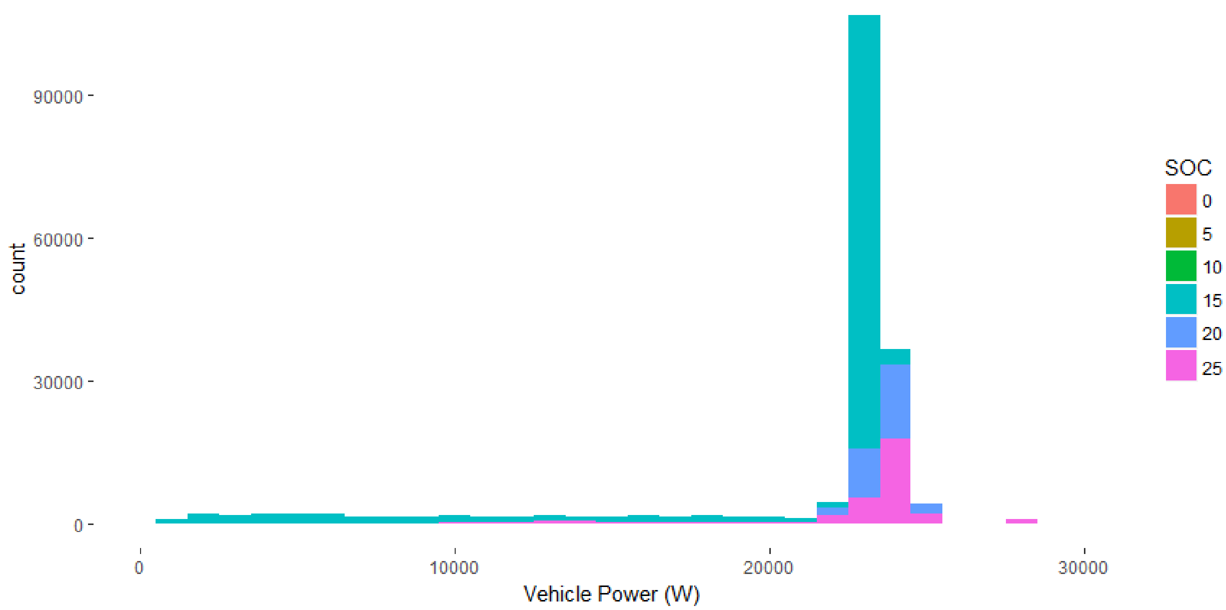

Figure 1-13
Histogram of Vehicle Charging Power Colored by Stationary Storage SOC

Without knowing what power the vehicles would charge at in a normal system we cannot know exactly how much time is lost in each individual charging session due to the grid power limit. However, the average charging power from the Kapolei Commons charger is 77% of the average in the Ward Ave. chargers, meaning that the charging time to deliver the same amount of energy is 1/.77 = 1.3 times longer than it would be in a normal charger. Over November and December, customers spent a cumulative 318 hours charging at the Kapolei Commons charger. This would be smaller by 318/1.3 = **73 hours** if it were a normal DCFC.

Customer Minutes Saved by Stationary Storage

The base case for this comparison is now a 25 kW DCFC with no storage. This simulates a case where there is a 25kW grid power limit but no storage was installed. Calculating how much time the stationary storage saved given a grid power limit of 25 kW is relatively straightforward. To do this, the amount of energy delivered by the stationary battery is converted to time saved by dividing by the 25 kW limit. The total amount of energy delivered by the battery is 545 kWh in the dataset involving mostly November and December 2017 data, which represents a savings of **21.8 customer hours** over those two months.

Simulated Commercial Customer Demand Charge Reduction

For this section, we look at a hypothetical commercial customer under Hawaii Electric Company's Schedule J rates (demand rate = $11.69/kW-mo, energy rate = 16.9734 cents/kWh). This customer has to pay the energy and demand charges incurred by the DCFC. The two options being explored are a case when this customer has the stationary energy storage system (so pays energy and demand charges based on the grid power) and a case where they do not (so pays energy and demand charges based on the DCFC power). The purpose will be to calculate the energy bill savings the stationary storage provides, which could be an input to a cost-benefit analysis to determine whether or not it makes sense to install stationary storage.

If the power being delivered to the vehicles is taken as what the facility's load power would be without a stationary storage system, then the demand charges would be $476 for November and $480 for December based on the maximum power (average in 15-min average) applied to the demand charges from the HECO rate structure: General Service Demand (Schedule J). The same process applied to the net power from the device results in demand charges of $274 for November and $273 for December. This means that the stationary storage would be saving this hypothetical customer an average of $204.5 per month in demand charges as long as we neglect the efficiency losses from any conversions between the billing meter and the DCFC.

Table 1-1
Demand Charges ($)

	Without Stationary Storage	With Stationary Storage	Savings
November	$476	$274	$202
December	$480	$273	$207

To provide any value from energy time shift, the stationary storage would have to charge during off-peak times and discharge during on-peak times. Currently, the stationary storage is not doing this. Additionally, because of the roundtrip efficiency losses from the stationary storage, the effect is to increase energy charges. In these two months, roundtrip efficiency losses in the stationary storage destroyed 51 kWh of energy, costing $8.65 over the two months. The energy cost is small compared to the demand charge reduction benefit. These results do not speak to the net cost or benefit of the system if all capital and operational costs are considered. Instead, they represent the real-world reduction in demand charges this system would have realized under schedule J rates.

Conclusion

This system is reducing the peak load drawn from the grid and is reducing customer charging times under the grid limit. However, a lack of energy capacity in the stationary storage results in slow charging for many customers with large vehicle storage capacities relative to a normal, unconstrained DC fast charger. It is impossible to perfectly predict the future and this result speaks to the value of energy storage to hedge against future growth in charging power/energy and the risk of installing an undersized storage system. For a potential commercial customer offering DC fast charging under schedule J rates, there is room for storage to reduce their demand charges which would have to be weighed in a full cost-benefit analysis.

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