Looking Behind the Meter – How Do Households with Solar + Storage Bridge the Gap Throughout Public Safety Power Shutoff (PSPS) Events

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ABSTRACT

In 2018, the California Public Utilities Commission (CPUC), working alongside CAL FIRE and other public safety officials, developed a High Fire-Threat map which identified areas that are at extreme risk or elevated risk for wildfires. The CPUC also built upon earlier rules providing authority to electric utility companies to shut down portions of the electric grid in response to wildfire threats. In October and November of 2019 these threats were realized, compelling electric utility companies to exercise their authority to carry out Public Safety Power Shutoff (PSPS) events. As a result, hundreds of thousands of electric customers were left without power – sometimes for days.

This paper goes “behind-the-meter" (BTM) and examines how energy storage and energy storage paired with on-site solar generation were being utilized by customers who lost power in response to PSPS events in 2019. This paper leverages data from energy storage systems rebated through the Self-Generation Incentive Program (SGIP) and operating throughout 2019.

Our results demonstrate storage systems paired with on-site PV generation are capable of charging and discharging throughout outages to provide customer resiliency. Systems paired with on-site solar were uniquely capable of riding out long duration utility power shutoffs – sometimes for 3 days – because the energy storage system could charge directly from solar. These results help inform how these BTM resources are behaving and providing benefits to customers throughout PSPS outages.

Introduction

The Self-Generation Incentive Program (SGIP) was established legislatively in 2001 to help address peak electricity problems in California (AB 970). The SGIP is funded by California’s electricity ratepayers and managed by Program Administrators (PAs) representing California’s major investor-owned utilities (IOUs). These PAs include Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), Southern California Gas Company and the Center for Sustainable Energy (CSE), which implements the program for customers of San Diego Gas and Electric (SDG&E). The California Public Utilities Commission (CPUC) provides oversight and guidance on the SGIP.

Since its inception, the SGIP has provided incentives to a wide variety of distributed energy technologies including combined heat and power (CHP), fuel cells, solar photovoltaic (PV) and wind turbine systems. The program has evolved since 2001, with eligibility requirements, program administration and incentive levels all changing over time in response to California’s evolving energy landscape. One key evolution is the contribution of energy storage technologies within the SGIP.

Beginning in Program Year (PY) 2009, energy storage systems that met certain technical parameters and were coupled with eligible SGIP technologies (wind turbines and fuel cells) qualified for incentives. Eligibility requirements changed during subsequent years. In PY 2011, standalone storage systems – in addition to those paired with SGIP eligible technologies or PV – were made eligible for incentives.

In 2016, the CPUC issued Decision (D.) 16-06-055, which, among other changes, revised how the SGIP is administered. Beginning with PY 2017, the SGIP is now administered on a continuous basis. This change was made largely to curb potential issues with incentives being depleted during program opening, as the program is typically oversubscribed. D. 16-06-055 also supplemented the first-come, first-served reservation system with a lottery.

More recently, the CPUC issued D. 19-09-027 that established an SGIP equity resiliency budget. To help deal with critical needs resulting from wildfire risks in the state, D. 19-09-027 set-aside the equity resiliency budget for households that have suffered two or more PSPS events, vulnerable households located in Tier 2 and Tier 3 High Fire Threat Districts (HFTD), critical services facilities serving those districts, and customers located in those districts that participate in low-income/disadvantaged solar generation programs or have critical medical equipment that requires electricity.

Along with these program budget changes, the CPUC built upon earlier rules providing authority to electric utility companies to shut down portions of the electric grid in response to wildfire threats. In October and November of 2019 these threats were realized, compelling electric utility companies to exercise their authority to carry out Public Safety Power Shutoff (PSPS) events. As a result, hundreds of thousands of electric customers were left without power – sometimes for days. This policy of de-energization of the grid has significant public policy and public health ramifications, especially for vulnerable individuals and communities, and the essential services and equipment they rely upon. As the SGIP program administrators begin providing incentives to customers located in these high-risk areas, it is important to understand how and if these BTM resources are providing benefits and services to those that need it the most.

Study Objectives

This paper is part of a much larger impact evaluation conducted by Verdant Associates in response to the SGIP Measurement and Evaluation (M&E) Plan developed by the CPUC, in consultation with the PAs. The M&E plan calls for a series of annual impact evaluations focused on energy storage technologies. This plan covers program years 2016 – 2020 and calls for several metrics to be reported for SGIP energy storage systems, including but not limited to:

- GHG emissions differentiated between residential and nonresidential systems, and between systems paired with renewable generation and non-paired systems.
- Timing and duration of charge and discharge on an average basis, and identification of groups of storage systems exhibiting certain trends in the timing of charge and discharge.
- Quantification of any contribution of energy storage projects to grid services where that storage substituted for and replaced planned investment into grid services.

While the primary objectives of the impact evaluation are to assess the ability of storage technologies to meet SGIP objectives to provide environmental benefits, improve operations of the grid, and achieve market transformation for distributed energy resource technologies, secondary objectives were identified throughout the course of the evaluation. One secondary objective developed was to better understand how behind-the-meter (BTM) energy storage and energy storage paired with on-site solar generation were being utilized by customers who lost power in response to Public Safety Power Shutoff (PSPS) events in 2019. SGIP systems operating throughout 2019 were not subject to any changes regarding how incentives are allocated across the equity resiliency budget. Participants and project developers in 2019 were not required to utilize SGIP storage systems in ways that would alleviate risk during PSPS events because the equity resiliency budget was not funded until 2020. However, given the real-world threats associated with these severe weather events and the associated grid de-energization in response to PSPS events, this paper examines how SGIP participants utilized their storage systems throughout these outages. Figure 1 presents five key research questions this paper aims to answer.

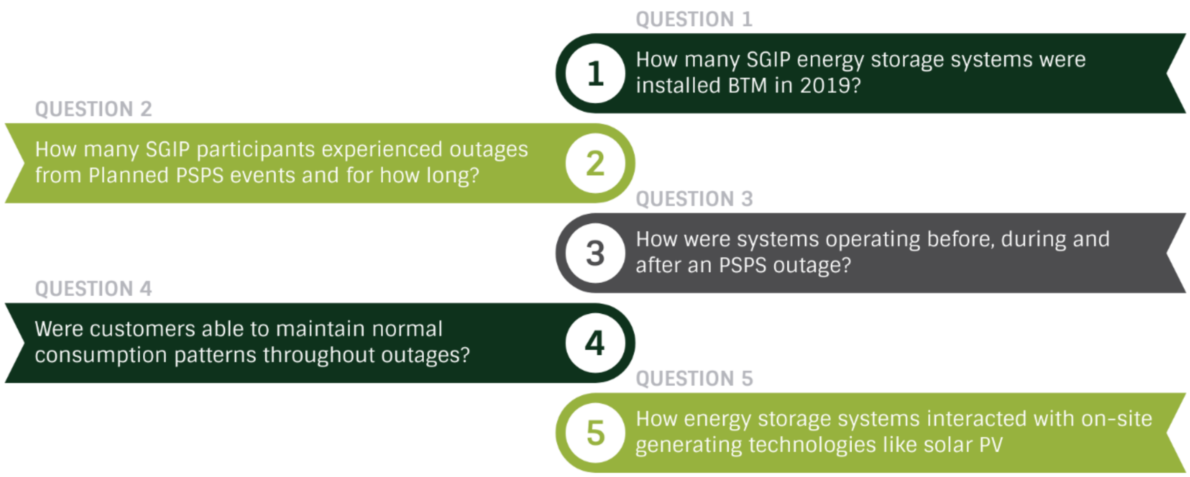

Figure 1. Research questions

SGIP Population Overview

The 2019 SGIP Energy Storage Impact Evaluation was an assessment of energy storage systems receiving an SGIP incentive on or before December 31, 2019. Figure 2 shows growth in SGIP energy storage in project count over time. The storage population in the 2019 study is represented by light green bars below. By the end of 2019, the SGIP had provided incentives to 8,875 systems representing almost 187 MW of rebated capacity. As evident below, the program has grown dramatically since that evaluation, with the residential sector increasing in size by over 180 percent. As of 10/20/2021 when the SGIP project list was last reviewed, the SGIP had incented 22,500 systems representing almost 1,000 MWh of capacity. This paper relies exclusively on data from the 2019 evaluation, but the magnitude in project growth – especially within the small residential and equity resiliency budget categories – and the continued threat and growing frequency of PSPS events since 2019 – provides a glimpse into how many more potential electric customers with BTM energy storage are being affected by these outages.

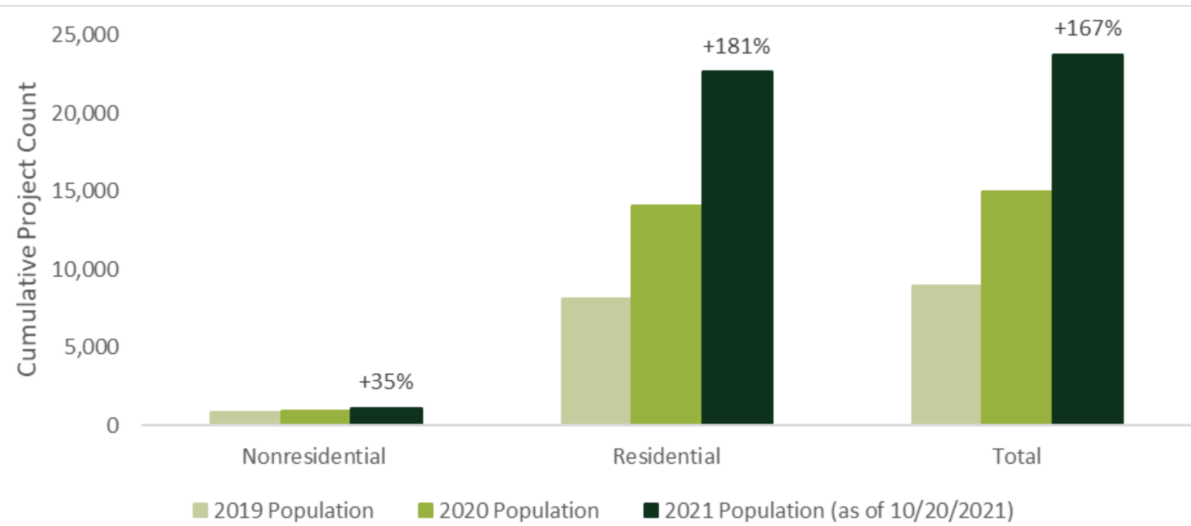

Figure 2. SGIP storage cumulative growth by upfront payment year.

Decision 19-09-027 passed in late 2019, and the sample of storage systems for the 2019 evaluation were drawn to develop population impacts that satisfied the requirements of the SGIP M&E plan, rather than to directly develop impacts associated with PSPS outages. At the time the research plan was developed for the 2019 impact evaluation, D.19-09-027 had not been passed and no PSPS events had been called in 2019. As a result, the forthcoming analysis includes systems as a sample of convenience. However, the research planning and sample design of future evaluations does take D.19-09-027 and PSPS events into account. Furthermore, the most robust set of data Verdant acquired to conduct this analysis were PG&E SGIP participants. Most of the PSPS outages in 2019 occurred in PG&E territory and PG&E provided the most complete dataset of outage events throughout 2019. This paper focuses on this subset of the SGIP population.

SGIP PSPS Sample Overview

Figure 3 summarizes the total count of PG&E projects. In 2019, residential projects represented the vast majority of incented SGIP storage systems (93%). Nonresidential projects represented the remaining 7%. However, residential systems represented much less in terms of overall system capacity (35%). While residential storage systems are generally in the 4.9 kW to 9.9 kW range, nonresidential systems are almost always larger and range in size from roughly 5 kW to over 2,500 kW. Of the 3,092 residential systems, 66 (or 2%) experienced at least one PSPS event outage in the 2019. Of those 66, thirteen (20% of PSPS customers, about 0.5% of residential customers) were in our original sample of projects. Eleven of those thirteen energy storage systems are paired with on-site solar generators.

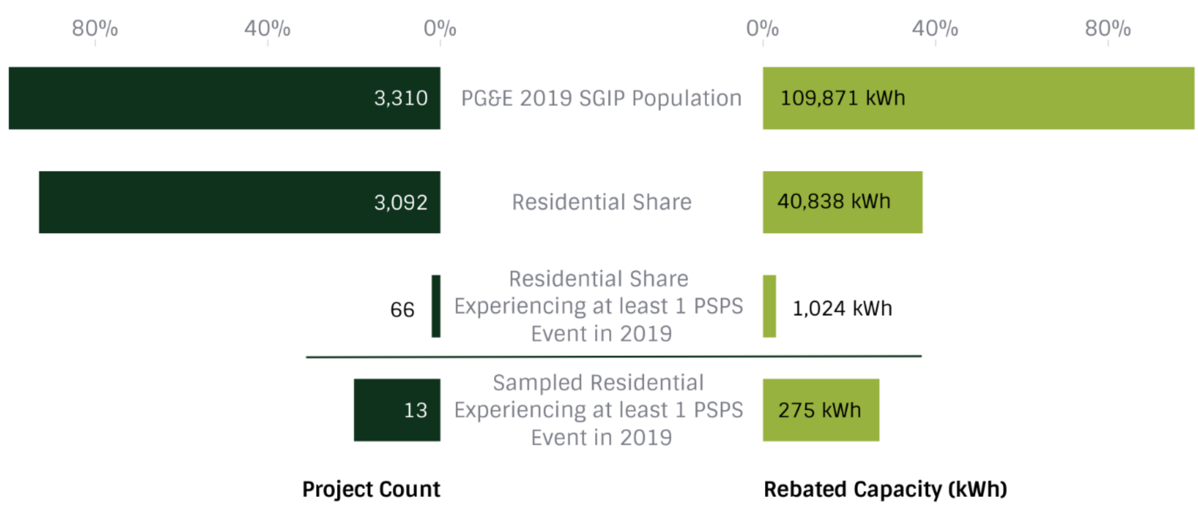

Figure 3. PG&E residential SGIP storage population and PSPS event history (2019).

SGIP PSPS Performance Overview

The forthcoming PSPS performance analysis was conducted throughout time periods where most or all the sampled projects experienced an outage. Given the small sample size and the limited number of events called in 2019, this allowed for the most comprehensive review of BTM storage performance. Figure 4 presents the total count of sampled projects (left bars) experiencing a PSPS outage during the days presented in October, and the right bars present the average outage duration for these customers. We observe the most extensive outages affecting the greatest number of SGIP participants beginning on 10/26 and extending through 10/28. As a result, our analysis focuses on that time period.

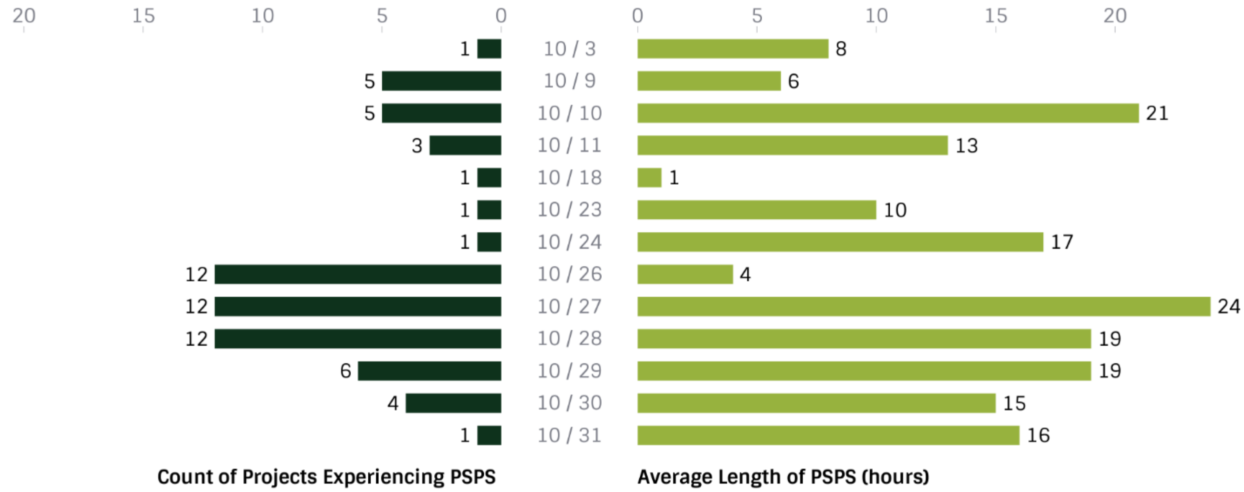

Figure 4. Count of PG&E SGIP projects experiencing PSPS events in October (2019).

The following heatmaps illustrate the hourly performance of energy storage systems paired with on-site PV throughout 10/24 – 10/30 as a percentage of the energy capacity of the storage system. The average power of these systems was roughly 7.7 kW with an average duration of 2.5 hours (19.2 kWh).

Figure 5 presents the average hourly net charge (red) or discharge (green) of the storage systems along with the average hourly PV production normalized by the storage kWh capacity. System charging occurs during early morning PV generating hours which is consistent with all SGIP residential energy storage systems paired with PV. This behavior is likely motivated by the federal solar tax credit, also known as the investment tax credit (ITC). For residential customers, the ITC is available to customers installing storage if the storage system is only charged by on-site generation like solar.

Discharging for this system configuration occurs predominantly in the late afternoon and early evening when PV generation wanes. We observe discharging throughout on-peak hours on Friday 10/24 and charging from PV on Saturday 10/25. The batteries are then mostly idle throughout the remainder of the weekend – when there are no on-peak hours for customers to conduct energy arbitrage. The PSPS event begins on Sunday evening, 10/26, and we observe the energy storage systems beginning to discharge immediately. The batteries continue to discharge about 3% of capacity per hour until the morning of 10/27, when the systems charge again from paired PV. All sampled customers did NOT have power throughout that entire day, but the combination of on-site PV and energy storage discharge allow the customers to maintain some level of comfort until the power is restored in the late afternoon of 10/28.

We also observe a change in PV generation throughout the two-day periods of the event. Prior to the outage and thereafter, peak PV production represents roughly 25% of the energy capacity of storage, but on 10/27 and 10/28, peak production lowers to 14% and 16%, respectively. While our team could not confirm why that is, it is likely that reductions in peak and overall solar PV generation throughout the events are a result of solar output curtailment. Excess PV generation cannot be exported to the grid throughout an outage, so systems are likely configured to curtail solar output to balance supply and demand behind the meter.

	Net Discharge kWh / Capacity kWh							PV Generation kWh / Capacity kWh						
Hour	24	25	26	27	28	29	30	24	25	26	27	28	29	30
0	0%	0%	0%	3%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%
1	0%	0%	0%	3%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
2	0%	0%	0%	3%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	0%	0%	0%	3%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
4	1%	1%	0%	2%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
5	0%	1%	0%	3%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%
6	0%	1%	0%	2%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%
7	1%	0%	0%	-1%	-1%	0%	0%	3%	3%	3%	2%	2%	2%	2%
8	-1%	-5%	-1%	-5%	-5%	-1%	-1%	9%	9%	9%	8%	6%	7%	8%
9	-3%	-6%	0%	-6%	-5%	0%	-1%	15%	15%	15%	10%	11%	12%	13%
10	-5%	-6%	-1%	-9%	-12%	-3%	-3%	21%	21%	21%	13%	16%	20%	23%
11	-4%	-13%	-1%	-10%	-9%	-5%	-2%	24%	25%	24%	13%	16%	24%	25%
12	-4%	-8%	1%	-9%	-5%	-1%	-2%	25%	24%	24%	14%	15%	22%	24%
13	-1%	-3%	1%	-4%	-6%	0%	-3%	20%	20%	21%	10%	14%	19%	18%
14	3%	0%	0%	-1%	-3%	0%	-3%	14%	14%	15%	6%	10%	14%	13%
15	8%	0%	-1%	1%	-1%	0%	3%	6%	7%	7%	4%	5%	7%	6%
16	3%	0%	1%	3%	-1%	1%	5%	1%	2%	1%	1%	1%	1%	1%
17	4%	0%	1%	5%	-1%	1%	5%	0%	0%	0%	0%	0%	0%	0%
18	3%	0%	1%	4%	1%	0%	3%	0%	0%	0%	0%	0%	0%	0%
19	3%	0%	3%	4%	1%	0%	2%	0%	0%	0%	0%	0%	0%	0%
20	3%	0%	3%	4%	1%	0%	3%	0%	0%	0%	0%	0%	0%	0%
21	1%	0%	4%	3%	-2%	0%	1%	0%	0%	0%	0%	0%	0%	0%
22	0%	0%	3%	3%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%
23	0%	0%	3%	3%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 5. Average hourly discharge, PV generation or charge kWh for 10/24 – 10/30.

Figure 6 presents the average hourly net load and household consumption as a percentage of the kWh capacity during the event period. We observe, in general, customers importing energy from the grid during late afternoon through early morning hours (green), followed by a net export of excess PV generation during non-outage periods (red). The outage period is quite clear in the graphic, from 8 pm on 10/26 through 2 pm on 10/28, where we observe energy storage systems discharging and on-site PV still generating (Figure 5). When power is restored on 10/28, the same pattern of import/export can be observed. But what's going on behind-the-meter when grid interconnection is interrupted from a PSPS event? The pattern and magnitude of storage charge and discharge, combined with on-site generation from PV, allow the customer to maintain some level of comfort throughout the outage. This behavior is presented on the right side of the figure. We observe household activity ramping up on 10/24 and extending throughout the weekend. We then observe average consumption during event periods. However, consumption does not zero out like load does throughout these times. Some customers are capable of either reducing energy consumption or have their energy storage system connected to a dedicated panel circuit. Once the event is over, household consumption increases closer to what it was the previous weekend. This behavior illustrates how impactful BTM storage paired with on-site PV can be during outage periods, and the potential resiliency these technologies can provide customers experiencing these events.

	Net Load kWh / Capacity kWh							Consumption kWh / Capacity kWh						
Hour	24	25	26	27	28	29	30	24	25	26	27	28	29	30
0	9%	5%	11%	0%	0%	3%	8%	7%	5%	10%	3%	3%	4%	7%
1	8%	4%	7%	0%	0%	3%	7%	7%	4%	6%	3%	2%	3%	6%
2	8%	3%	5%	0%	0%	3%	5%	7%	3%	4%	2%	2%	3%	3%
3	5%	3%	6%	0%	0%	4%	7%	4%	3%	4%	3%	2%	3%	4%
4	5%	4%	5%	0%	0%	3%	6%	4%	4%	3%	2%	2%	3%	4%
5	5%	5%	6%	0%	0%	4%	6%	5%	4%	4%	3%	2%	4%	4%
6	5%	6%	6%	0%	0%	4%	8%	5%	6%	5%	2%	2%	4%	8%
7	2%	4%	7%	0%	0%	4%	3%	7%	8%	9%	4%	4%	5%	6%
8	-3%	3%	1%	0%	0%	1%	0%	6%	9%	8%	4%	4%	7%	7%
9	-3%	0%	-5%	0%	0%	-7%	-6%	11%	11%	10%	3%	5%	7%	8%
10	-6%	-7%	-11%	0%	0%	-10%	-12%	12%	12%	11%	5%	3%	9%	9%
11	-8%	-3%	-13%	0%	-2%	-13%	-16%	16%	12%	14%	4%	6%	8%	8%
12	-9%	-6%	-10%	0%	0%	-13%	-17%	15%	14%	19%	3%	9%	8%	6%
13	-7%	-4%	-7%	0%	0%	-12%	-13%	14%	16%	19%	4%	7%	9%	4%
14	-3%	0%	-1%	0%	2%	-7%	-5%	17%	15%	16%	5%	9%	8%	7%
15	-1%	4%	8%	0%	2%	-1%	-3%	15%	12%	15%	6%	7%	7%	6%
16	6%	10%	12%	0%	7%	6%	3%	12%	11%	13%	4%	6%	8%	10%
17	10%	12%	7%	0%	10%	8%	5%	14%	12%	8%	5%	9%	7%	9%
18	9%	13%	7%	0%	7%	8%	10%	12%	14%	6%	4%	7%	7%	11%
19	7%	12%	4%	0%	6%	11%	10%	10%	11%	6%	4%	6%	8%	9%
20	9%	10%	1%	0%	8%	13%	11%	12%	8%	4%	4%	9%	15%	12%
21	11%	9%	1%	0%	11%	9%	10%	12%	7%	4%	3%	9%	9%	10%
22	11%	10%	0%	0%	8%	9%	10%	11%	9%	3%	3%	8%	8%	10%
23	9%	17%	0%	0%	6%	8%	12%	10%	17%	3%	3%	7%	7%	11%

Figure 6. Average hourly export, import or consumption kWh for 10/24 – 10/30.

These heatmaps were transformed into time series load shape profiles for the same period (10/24 – 10/30). Figure 7 reveals the shape and magnitude of storage discharge, PV generation, grid interconnection and customer load. We observe 1) the much more significant charging of energy storage during the event period (gray shaded area going negative), 2) the reduction in overall PV generation during the events, 3) grid interconnected load being exported (light green area going negative) and going to zero throughout the outage, and 4) less household consumption throughout the event period when compared to non-event days, but the customers are not without power.

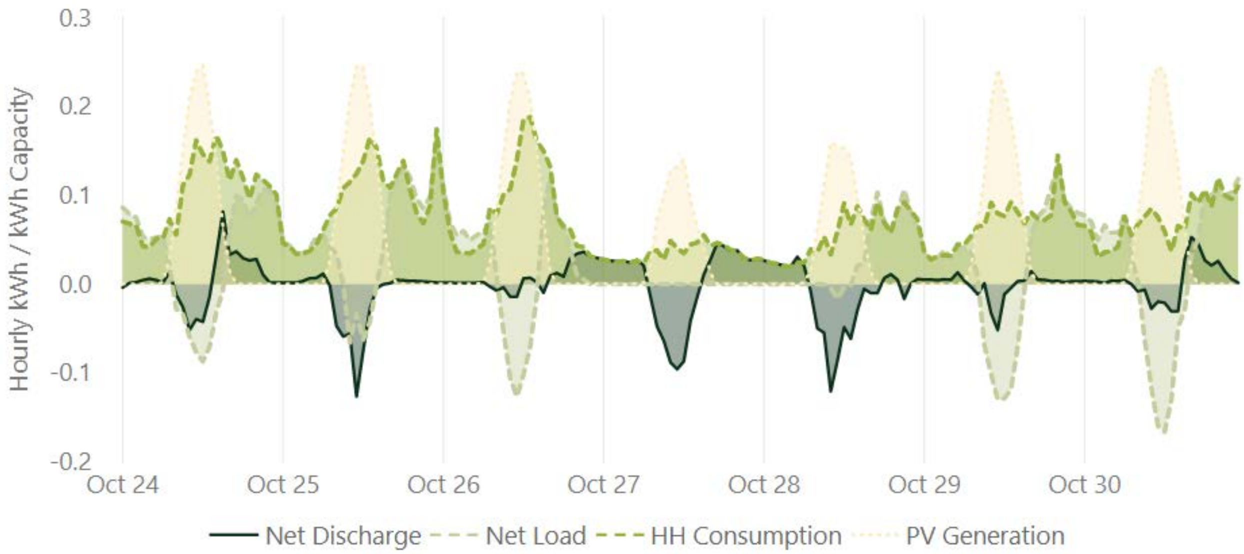

Figure 7. Observed residential behavior during PSPS events (with solar PV).

We also examined the impacts for the sample of customers experiencing outages and compared those impacts to conditions when there was no outage. We reviewed the average hourly net discharge, PV generation, net load, and consumption for customers when they were experiencing PSPS events and compared those impacts to how those same customers were behaving when no outages were occurring. This analysis was limited to the month of October and the hourly averages only include weekdays, given the observed differences in household weekend activity. Figure 8 conveys the same information as the former analyses – storage paired with on-site generation provides resiliency to customers experiencing PSPS outages.

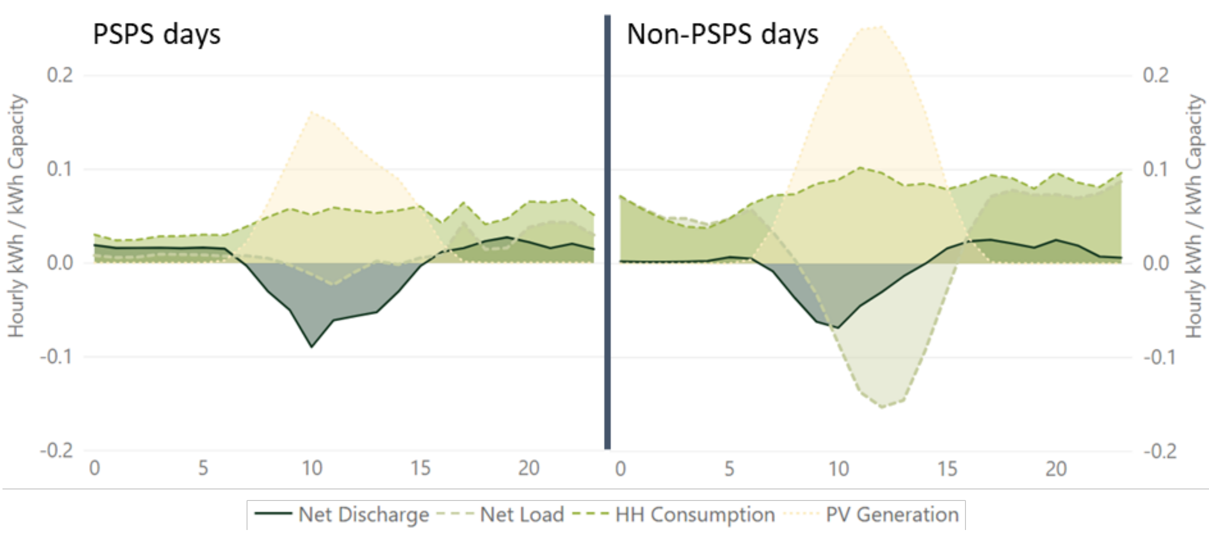

Figure 8. Observed average hourly residential behavior during PSPS events and non-PSPS events (weekday only).

Key Takeaways

As discussed previously, by December 31st of 2019, the SGIP had provided incentives to 8,875 energy storage systems, installed across multiple customer sectors. Of that total, 3,310 (37%) were installed in PG&E territory. We requested and received electric outage information for all 3,310 energy storage systems throughout 2019, along with the description of the outage cause. Of that total, 66 SGIP residential participants (2%) experienced at least one PSPS outage throughout 2019. We reviewed our sample of systems and determined that we had evaluated 13 of them for the 2019 impact evaluation (11 of the 13 were also paired with PV). Ten nonresidential customers also experienced PSPS outages. The small sample size precludes a rigorous evaluation of PSPS customer impacts, but the data do provide some insights into how storage is being utilized to provide customer relief during long duration outage periods. At a high level, the data confirm:

- Customer electric load decreased to zero throughout multiple periods in October of 2019. The exact timing and duration of these PSPS outages is predicated on where these customers are located on the distribution system, but they occurred throughout three general time periods:
  - 10/9 through 10/11
  - 10/23 through 10/24
  - 10/26 through 10/31
- Event durations range from one to two hours to 24 hours – and can extend throughout multiple days.
- There was no storage activity for the 10 nonresidential participants. During event periods, load goes to zero, but storage systems either remain idle or go offline throughout the event.
- Reductions in PV generation, on average, throughout the events. This could be weather/smoke related or a consequence of inverter design.
- There is a wide variety of storage activity for residential customers:
  - For those systems paired with solar PV, we observe the storage system satisfying consumption at the home. While consumption is lower than prior to or after the events, customers maintain some level of comfort.
  - Systems are charging from on-site solar generation, so they can sustain their normal energy consumption behavior for long durations during shutdowns.
  - While not a focus of this study, there were two energy storage systems not paired with PV. We observe the storage systems discharging, but only at much lower levels of magnitude – likely to maintain service on a few critical loads. Without on-site generation, however, these systems ultimately only provide customer support for as long as the battery can maintain a state of charge.

Next Steps

This analysis was conducted on a subset of BTM energy storage systems throughout 2019. This occurred prior to the passage of D. 19-09-027 and the creation of the Equity Resiliency Budget. Since that time, the CPUC issued D. 20-01-021. The decision authorized the collection of ratepayer funds totaling $166 million dollars per year from 2020 to 2024. This decision increased the financial incentive budget for energy storage technologies to 85% of total SGIP funding. As shown in Figure 9, the program has increased in size dramatically, first in 2020 in the small residential storage category, and again in 2021. The new equity resiliency budget ushered in almost 2,800 new systems in 2021, which were incented specifically to vulnerable households located in Tier 2 and Tier 3 High Fire Threat Districts (HFTDs) or customers who have been subject to two or more PSPS events. As a result, well over 500 PG&E SGIP participants experienced at least one PSPS event in 2020, along with many others across other IOU service territories. This number likely continued to rise in 2021 with more customers installing paired storage and solar systems, along with more frequent and catastrophic fire events. As we continue to track the performance and benefits accrued from SGIP incented energy storage systems to customers, further research will provide more clarity and understanding of how these distributed resources can be best utilized to provide program-level objectives, participant benefits and societal goals moving forward.

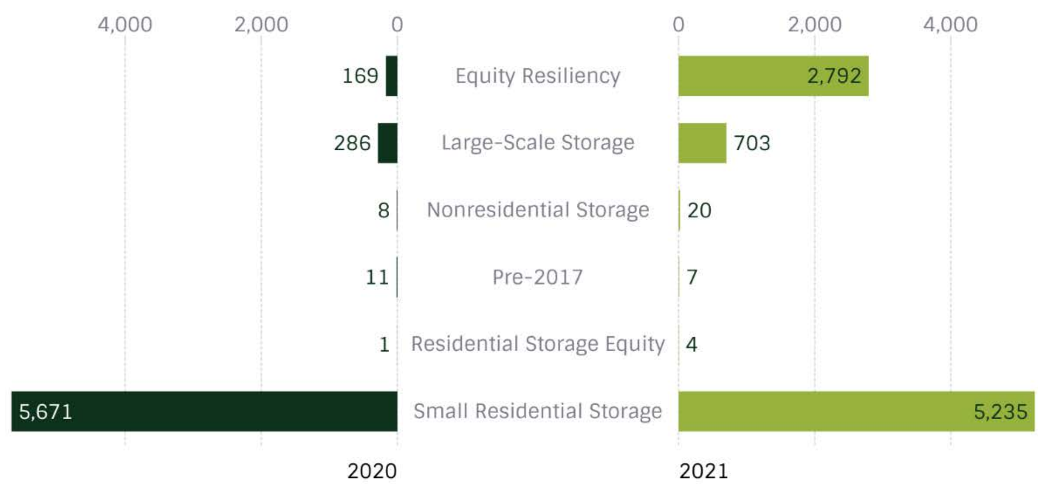

Figure 9. Change in SGIP storage population since 2019 (by budget category).

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