NAVIGANT CONSULTING

Self-Generation Incentive Program

PV Performance Investigation

Presented to

The SGIP Working Group

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Presented by

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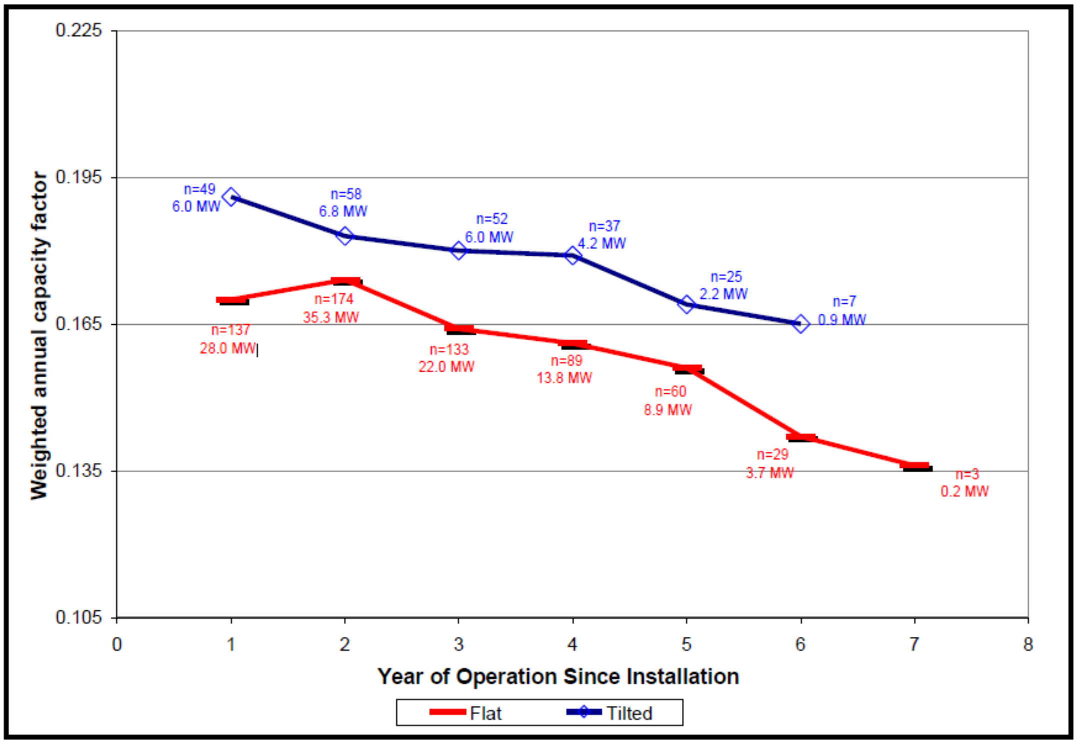
Section 1. Introduction

The 2008 Self-Generation Incentive Program (SGIP) Impact Evaluation[1] revealed a significant decline in capacity factor of photovoltaic (PV) systems as they age and stated that "Understanding reasons for the differences requires additional process evaluation information." Figure 1 shows the graphic from this report illustrating the decline in capacity factor.

[1] Itron, Inc. "CPUC Self-Generation Incentive Program Eighth-Year Impact Evaluation – Revised Final Report", July 2009. Vancouver, WA.

Figure 1. PV Annual Capacity Factor versus Year of Operation, from SGIP Eight Year Impact Evaluation[2]



Source: Itron, Inc.

This report documents the examination of performance decline for PV systems in the SGIP. Performance decline and related metrics were determined from metered hourly system output data for 389 participating sites across California. Phone interviews with 35 sites were used to enhance findings. A separate report examines performance decline for combined heat and power (CHP) systems.

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[2] Ibid.

The SGIP PV projects are almost exclusively non-residential: residential PV installations may have significantly different performance and host experience.

1.1 *Causes of Performance Variation*

This analysis began with an enumeration of the reasons for a *perceived* variation in individual PV system performance over time. Five general types of perceived variation were identified and are described below:

- **Type 1 - Natural year-over-year variation in solar radiation at the site -** Total annual solar insolation can vary by 10 percent or more at a given site. As solar insolation directly affects PV system output, significant annual variation attributable to weather variation is expected. Annual PV performance can be normalized by solar insolation data from nearby weather stations to reduce this variation.

- **Type 2 - Changes to PV system that affect the level of output –** The output of PV systems is affected by the following changes to the PV system and its environment:
    - Degradation of PV materials.
    - Dirt accumulation.
    - Changes in shading.
    - Changes in system – panel increase, decrease, or replace, inverter replacement.

  The accumulated impact of these influences should be observable in the system output data as statistically significant deviations from initial system output.

- **Type 3 - Changes to the PV system that eliminate output (i.e., no output after change) –** The output of PV systems can be reduced to zero by:
    - Failures of electrical connections.
    - Failures of inverter (tripping and catastrophic failure).
    - Disconnection of PV system from site electrical system.
    - Shading.[3]

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[3] For a demonstration of the exaggerated impact of shading on a single-string, grid-tied PV system, see Deline, C. *Partially Shaded Operation of a Grid-Tied PV System* 34th IEEE Photovoltaic Specialists Conference, Philadelphia, PA June 2009. Conference pre-print version available at http://www.nrel.gov/docs/fy09osti/46001.pdf. In this experiment,

The accumulated impact of these influences should be observable in the system output data as times of zero output during daylight hours.

» **Type 4 - Changes to data acquisition that affect the reported level of output –** PV system output is assumed from data acquisition reports. However, data acquisition systems are subject to modification in reported output due to:
  - Transducer drift – over time, the sensors measuring power or current may drift from calibration.
  - Change in transducer placement – the placement of the sensors can affect the reported output; sensors may be unintentionally moved.

  The accumulated impact of these changes would distort the perceived effects of Type 2 changes.

» **Type 5 - Changes to data acquisition system that eliminate reported output (i.e., no output reported after change) –** A report of no output, or of missing data, can be the result of the following data acquisition related occurrences:
  - Failure of data acquisition system (including communication equipment and systems).
  - Termination of data acquisition service.
  - Transducers removed or displaced from PV system (possibly unknowingly during a repair/modification).

  The accumulated impact of these changes would distort the perceived effects of Type 3 changes if the resulting output data recorded as zero output, rather than missing data; missing data is directly observable in the output data.

It is important to emphasize that this is *perceived* variation because we are examining the output of the data acquisition system, not the PV systems themselves. Variation in output could just as

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shading was demonstrated to result in a reduction in power (ratio of output power with shading to output power without shading) of over 30 times the ratio of shaded area to full panel area.

reasonably (but less likely) come from changes in the data acquisition system as from the PV system itself. Type 4 and Type 5 variation come for data acquisition: Type 5 variation is controlled for by excluding times of data gaps from the analysis; Type 4 variation is largely controlled for by looking at average behavior over many systems, for which transducer drift is expected to be unbiased. This phase of the degradation analysis does not include an investigation of Type 4 variation.

Performance can be disaggregated into 1) power production and 2) ability to provide produced power. Degradation could be due to Type 2 and Type 3 changes, respectively. Low/no perceived output could also be due to data acquisition failures.

1.2 Operating Assumptions for the Analysis

Based on this categorization, several operating assumptions were necessary to proceed with this analysis:

1) Performance could be normalized by solar insolation at nearby, geographically appropriate weather stations to minimize the effects of weather induced variation without biasing results across the population. This implies that while in some cases (years, sites) the weather station was sunnier than the PV site, in others the PV site was sunnier than the weather station and, on average, there was no difference in total annual insolation between the PV site and weather station.

2) Daylight hours of zero perceived output were indeed hours of zero output (Type 3 variation), and not data acquisition reporting problems (Type 5 variation).

3) Perceived variation due to data acquisition system changes (Type 4 variation) were insignificant.

4) Daylight hours with missing output data were the result of the data acquisition system (Type 5 variation), and that all Type 5 variation resulted in data gaps, rather than reported zero output. Therefore, performance during times of data gaps was assumed to be the same as performance during times of available data.

1.3 Select Findings

Based on the data available for metered systems, we observed that:

1) The most significant cause for the perceived decline in annual capacity factor with age (as noted in the SGIP Eighth-Year Impact Evaluation) is actually in *increase* in capacity factor of newer systems, relative to earlier systems; the year-over-year trend a given systems performance is much more stable.

Table 1 summarizes the average capacity factor by first year of operation and system age. The blue bars indicate the relative magnitudes of each value: the shortest bar represents a value of 0.131 and the longest bar represents a value of 0.193. The clear declining trend in capacity factor by age is seen in the bottom row of data, particularly for ages 4 through 6. However, the average values for systems of all ages (last column on the right) show that new system have higher capacity factors each year. The trend in capacity factor as those systems age (first seven rows of the table) is much less significant.

Table 1. Annual Capacity Factor by First Year of Operation and System Age

First Year of Operation	Age							
	0	1	2	3	4	5	6	All Ages
2002	0.131	0.162	0.157	0.149	0.145	0.157	0.138	0.152
2003	0.145	0.161	0.157	0.153	0.164	0.154		0.156
2004	0.165	0.166	0.160	0.170	0.157			0.164
2005	0.166	0.171	0.175	0.174				0.172
2006	0.168	0.191	0.189					0.185
2007	0.179	0.184						0.182
2008	0.193							0.193
All Years	0.164	0.171	0.168	0.165	0.157	0.155	0.138	0.165

2) The average performance of individual systems over time is reasonable.

Output during times when systems are online and producing power declines by 0.8 percent (relative to the first year of output) per year, after controlling for annual variation in solar insolation. This decline in system performance is on par with manufacturer claims (typically 20 percent degradation after 20 years) and observed performance from other studies.[4]

[4] For example, a 2002 NREL study on this topic observed 0.7 percent degradation per year.

On average, systems are online and producing power 97 percent of daytime hours; and this on-time decreases at a rate of 0.4% of all daylight hours, per year.

Table 2 summarizes these results. The results are presented by each SGIP Program Administrator (PA). The SGIP PAs are Pacific Gas and Electric Company (PG&E), Southern California Edison Company (SCE), Southern California Gas Company (SCG), and the California Center for Sustainable Energy (CCSE).

Osterwald, C.R. et al., *Degradation Analysis of Weathered Crystalline-Silicon PV Modules*, Proceedings of the 29th IEEE PV Specialists Conference, New Orleans, LA May 2002 and NREL document NREL/CP-520-31455. Pre-print available online via http://docs.google.com.

Table 2. Year-over-year trends in system performance, outages, and missing data

	Year-over-year percentage point trends		
PA	***Peformance during normal hours, relative to first year performance***	***Midday hours with zero/near-zero output, as a percentage of all midday hours***	***Missing data, as a percentage of all daytime hours***
PG&E	***-0.9%*** *[-1.3%,-0.4%]* *459*	***0.4%*** *[0.2%,0.6%]* *567*	***7.3%*** *[6.0%,8.6%]* *653*
SCE	***-1.0%*** *[-3.5%,1.4%]* *119*	***0.9%*** *[-0.1%,2.0%]* *220*	***8.0%*** *[5.3%,10.7%]* *260*
SCG	***-0.4%*** *[-1.5%,0.7%]* *67*	***0.0%*** *[-0.4%,0.5%]* *111*	***10.5%*** *[7.4%,13.6%]* *181*
CCSE	***-1.1%*** *[-1.8%,-0.4%]* *332*	***0.0%*** *[-0.5%,0.5%]* *381*	***0.0%*** *[-0.9%,0.8%]* *388*
ALL PAs	***-0.8%*** *[-1.3%,-0.4%]* *977*	***0.4%*** *[0.1%,0.6%]* *1279*	***5.7%*** *[4.9%,6.5%]* *1482*

3) **Nineteen percent of output data is missing, and percentage of all hours for which data is available decreases by 5.7 percentage points per year.**

There were significant differences in the amount of missing data across PAs, ranging from five percent for CCSE to 16 percent for PG&E, to 36 percent for SCE, to 43 percent for SCG. Additionally, the amount of missing data is significantly less in systems installed in 2004 or later than in systems installed in 2002 and 2003. These significant differences across time and PA suggest that the amount of missing data can be minimized through data acquisition implementation best practices.

Missing data and increases in missing data limit the ability to draw conclusions about subsets of the population and as systems age.

4) For this sites with the most significant performance variation, interviews revealed a range of host attention to system, widespread and frequent cleaning, and significant system failures.

Most of interviewed participants are not closely monitoring their systems – 46 percent of interviewed participants reported low levels of monitoring, and 28 percent reported no monitoring. As noted above, system performance and inverter performance does change over time; if these systems are not monitored, performance issues resulting in poor to no performance may persist.

Most systems are cleaned regularly – 86 percent of interviewed participants either clean their panels regularly or contract with others to clean their panels regularly.

PV systems are error prone – The notion of "plug and play" systems with high reliability because of the absence of moving parts is not entirely accurate:

- **Inverters** – 54 percent of interviewed participants experienced problems with their inverter performance. 34 percent did not, and 12 percent were not sure.
- **Panels** – 23 percent of interviewed participants had their panels replaced (at no cost to them) due to panel performance issues.

1.4 Report Organization

The remainder of this report describes the data analysis and interviewing efforts and results. Section 2 describes the data collection and cleaning process. Data analysis is described in Section 3. Section 4 describes the process of selecting sites for interviewing and summarizes findings from the interviews. **Error! Reference source not found.** provides conclusions and recommendations.

Section 2. Data Collection and Cleaning

Navigant Consulting (formerly Summit Blue) received PV output data for 389 SGIP projects with a total installed capacity of 72 MW. This data was matched to hourly weather data (solar insolation) at nearby weather stations. Weather data was used to determine daylight hours, and only daylight hours were considered for the analysis. Output data was disaggregated into hours of missing data, hours of zero/near-zero output, and all other hours (deemed "normal" hours). System performance during normal hours was used to estimate the aggregate impacts of system degradation, dirt accumulation, and shading changes on systems. The ratio of zero/near-zero output to normal output was used to estimate the aggregate impacts of system failures and catastrophic shading.[5] This section describes the data collection and cleaning process.

2.1 SGIP Participant Data

Table 3 summarizes the total installed capacity, average capacity per project , and number of projects in the dataset. In all of these tables, results are shown by PA and first year of operation. Projects are characterized by the year in which they became operational[6]: *not necessarily* the year that the project was approved by SGIP (which could be earlier) and not necessarily the first year for which adequate data was available (which could be later). The number of systems per year of installation is not cumulative meaning the count of systems for a particular year includes only those systems that became operational during that year, not the cumulative number of systems that became operational from the start of the program through that year.

[5] That is, shading resulting in zero/near-zero system output.

[6] Date of operation commencement was provided by Itron, Inc., along with the system output data.

Table 3. Total capacity, average capacity, and number of installations in dataset, by PA and system's first year of operation

PA		2002	2003	2004	2005	2006	2007	2008	All Years
PG&E	Total Capacity (kW)	1,800	4,424	7,120	8,764	8,803	10,219	2,359	*43,489*
	Average Capacity (kW)	100	116	183	325	352	365	214	*234*
	Count	18	38	39	27	25	28	11	*186*
SCE	Total Capacity (kW)	167	2,089	2,491	1,737	1,271	-	-	*7,755*
	Average Capacity (kW)	42	149	80	158	212	-	-	*118*
	Count	4	14	31	11	6	0	0	*66*
SCG	Total Capacity (kW)	369	4,026	747	326	1,563	-	-	*7,031*
	Average Capacity (kW)	62	201	249	81	313	-	-	*185*
	Count	6	20	3	4	5	0	0	*38*
CCSE	Total Capacity (kW)	934	1,455	1,294	4,383	3,408	2,284	-	*13,757*
	Average Capacity (kW)	233	145	81	118	162	208	-	*139*
	Count	4	10	16	37	21	11	0	*99*
ALL PAs	Total Capacity (kW)	3,270	11,994	11,653	15,210	15,045	12,503	2,359	*72,032*
	Average Capacity (kW)	102	146	131	193	264	321	214	*185*
	Count	32	82	89	79	57	39	11	*389*

2.2 *Annual Capacity Factor*

In addition to hourly output data, Itron provided the annual capacity factor for each system, as determined by Itron and detailed in the SGIP Eight-Year Impact Evaluation. Table 4 summarizes the average capacity factor by first year of operation and system age. The blue bars indicate the relative magnitudes of each value: the shortest bar represents a value of 0.131 and the longest bar represents a value of 0.193.

Table 4. Annual Capacity Factor by First Year of Operation and System Age

First Year of Operation	Age							
	0	1	2	3	4	5	6	All Ages
2002	0.131	0.162	0.157	0.149	0.145	0.157	0.138	0.152
2003	0.145	0.161	0.157	0.153	0.164	0.154		0.156
2004	0.165	0.166	0.160	0.170	0.157			0.164
2005	0.166	0.171	0.175	0.174				0.172
2006	0.168	0.191	0.189					0.185
2007	0.179	0.184						0.182
2008	0.193							0.193
All Years	0.164	0.171	0.168	0.165	0.157	0.155	0.138	0.165

This table is revealing: The clear declining trend in capacity factor by age is seen in the bottom row of data, particularly for ages 4 through 6. However, the average values for systems of all ages (last column on the right) tells a very different story: that new systems have higher capacity factors each year. For a particular first year of operation, the trend in capacity factor as those systems age is much less significant (and even increasing from one year to the next in some cases, most likely due to natural variation in solar insolation from year to year). **These observations combine to illustrate that the declining trend in capacity factor by age, as noted in the eighth-year impact evaluation, would more appropriately be characterized as an *increase* in capacity factor in newer systems; newer systems with high capacity factors inflate the average capacity for systems of low age, while the only systems in the dataset with higher ages are the older systems, which had lower capacity factors to begin with.**

2.3 *Meteorological Data*

In order to assess system performance, it was important to compare system output to solar insolation at each site. For hour-to-hour data, this was necessary to distinguish between daylight and non-daylight hours. For year-to-year comparisons, performance needed to be normalized for weather to minimize the influence of normal, year-over-year meteorological variation[7] on perceived performance.

Solar insolation data was collected from the California Irrigation Management Information System (CIMIS) website, sponsored by the California Department of Water Resources, Office of Water Use Efficiency. CIMIS provides historical hourly weather data for a collection of weather stations throughout the state. We considered only sites with data from January 1, 2002 through December 31, 2008 (the period for which we had project data) and only sites with 99.9 percent or more of data points present. This yielded a total of 101 weather stations.

Data from eligible sites was cleaned before using for the degradation analysis. The overall quality of the data appeared quite good; the only cleaning necessary was to fill in data gaps. Data gaps were filled with the average value from the same hour in the day immediately prior and the day immediately following the day of the gap.

2.4 *Matching Sites to Weather Stations*

Each SGIP site in the dataset was matched to the nearest geographically-appropriate weather station. Proximity was determined by Geographic Information System (GIS) analysis. Results were reviewed to identify any matches between a coastal site and inland weather station, or vice versa. We manually reassigned matches for these sites, using the nearest coastal weather station for coastal SGIP sites and the nearest inland weather station for inland SGIP sites.

2.5 *Data Characterization*

A dataset was created that contained an observation for each hour from the first output hour of the dataset to the end of 2008. Fields in this dataset include the recorded PV system output and the insolation at the matched weather station. Based on these fields, each record was characterized as:

1) A daylight hour or not (if the insolation value was above a minimum threshold).

[7] Observed year to year variation in annual solar insolation at the weather stations used for this analysis was as much as ten percent in several cases.

2) Having output data that was either:
    a. missing (data gap);
    b. below a minimum output threshold level (0.5 percent of rated capacity);
    c. above a maximum output threshold level (150 percent of rated capacity); or
    d. normal (anything not characterized as missing, below minimum, or above maximum).

These datasets, created for each project, were the basis of the degradation analysis.

The tables in the following subsection summarize the character of data provided: the percentage of daylight hours for which data was normal (Table 5), below the threshold level (0.5 percent of rated capacity, i.e., effectively no output) (Table 6 and Table 7), and missing (Table 8). No data points were observed to be above the maximum threshold (150 percent of rated capacity). Systems are categorized by PA and by the first year of operation. Results are weighted by system (i.e., each system has equal weight) rather than by installed capacity (i.e., greater weight for larger systems) to prevent larger systems from biasing character statements.

For each PA/year combination, three rows of data are shown. The first row (in bold) is the average value for all systems of that PA/year categorization. The second row is the 90 percent confidence interval of this estimate for the full population of SGIP systems. The third row is the number of systems with that PA/year categorization.

2.5.1 Normal Data

Table 5 summarizes the percentage of daylight hours for which data were normal. On average, 77 percent of hourly output data point systems were present in the dataset, and greater than the minimum threshold (0.5 percent of output). There were significant differences across PAs, ranging from 53 percent (SCG) to 91 percent (CCSE). There were also significant differences across the initial year of operation. Except for CCSE systems, systems installed in 2005 and 2006 had increases in this percentage, bringing the percentage of normal datapoints across all PAs up from 68 percent for systems installed in 2004 to 86 percent for systems installed in 2005. Non-normal data is further categorized as zero/near-zero, or missing: the following two subsections discussed these categories.

Table 5. Percentage of daylight hours for which data is normal, by PA and system's first year of operation

PA		2002	2003	2004	2005	2006	2007	2008	*ALL Years*
PG&E	estimate	**77%**	**59%**	**77%**	**88%**	**91%**	**93%**	**87%**	***80%***
	90% confidence range	[63%,90%]	[51%,68%]	[70%,84%]	[83%,92%]	[89%,94%]	[90%,95%]	[80%,95%]	*[77%,83%]*
	n	n = 18	n = 38	n = 39	n = 27	n = 25	n = 28	n = 11	*n = 186*
SCE	estimate	**50%**	**72%**	**44%**	**75%**	**70%**	-	-	***58%***
	90% confidence range	[36%,63%]	[58%,87%]	[36%,52%]	[65%,86%]	[45%,94%]	-	-	*[52%,64%]*
	n	n = 4	n = 14	n = 31	n = 11	n = 6	n = 0	n = 0	*n = 66*
SCG	estimate	**40%**	**38%**	**95%**	**72%**	**85%**	-	-	***53%***
	90% confidence range	[14%,65%]	[25%,52%]	[90%,101%]	[42%,102%]	[72%,99%]	-	-	*[42%,63%]*
	n	n = 6	n = 20	n = 3	n = 4	n = 5	n = 0	n = 0	*n = 38*
CCSE	estimate	**92%**	**93%**	**88%**	**90%**	**87%**	**98%**	-	***91%***
	90% confidence range	[89%,95%]	[92%,95%]	[84%,92%]	[88%,91%]	[81%,93%]	[97%,99%]	-	*[90%,93%]*
	n	n = 4	n = 10	n = 16	n = 37	n = 21	n = 11	n = 0	*n = 110*
ALL PAs	*estimate*	***68%***	***61%***	***68%***	***86%***	***87%***	***95%***	***87%***	***77%***
	90% confidence range	*[57%,78%]*	*[54%,67%]*	*[63%,73%]*	*[83%,89%]*	*[83%,91%]*	*[94%,97%]*	*[80%,95%]*	*[74%,79%]*
	n	n = 32	n = 82	n = 88	n = 79	n = 57	n = 39	n = 11	*n = 389*

2.5.2 Zero/Near –Zero Data

Table 6 summarizes the percentage of midday hours (11am to 2 pm) for which the output value was zero or near zero (less than 0.5 percent of the system's rated capacity). Only midday hours were considered to avoid misinterpreting the low output at dawn or dusk as an outage. The average across all systems is 3.0 percent. **The corollary to this is that, on average, SGIP PV systems are online and producing power 97% of the (daylight) time**. This does not vary considerably across PAs or years, suggesting a characteristic inherent to the PV systems, rather than the implementation. Zero output could be caused by failures requiring maintenance, temporary panel shading, inverter trips, or system disconnects for infrastructure adjustments or maintenance activities.

Table 6. Percentage of midday hours for which data is zero or near zero, by PA and system's first year of operation

PA		2002	2003	2004	2005	2006	2007	2008	*ALL Years*
PG&E	estimate	**1.6%**	**2.4%**	**2.7%**	**3.2%**	**1.0%**	**3.8%**	**1.2%**	***2.5%***
	90% confidence range	[1.0%,1.6%]	[1.3%,2.4%]	[1.2%,2.7%]	[1.4%,3.2%]	[0.5%,1.0%]	[1.7%,3.8%]	[0.2%,1.2%]	*[1.9%,2.5%]*
	n	18	38	39	27	25	28	11	*186*
SCE	estimate	**0.8%**	**2.7%**	**7.4%**	**1.9%**	**1.5%**	**-**	**-**	***4.6%***
	90% confidence range	[-3.7%,0.8%]	[1.1%,2.7%]	[7.4%,7.4%]	[1.5%,1.9%]	[-12.1%,1.5%]	-	-	*[1.9%,4.6%]*
	n	4	14	31	11	6	0	0	*66*
SCG	estimate	**3.5%**	**2.8%**	**0.2%**	**0.4%**	**9.1%**	**-**	**-**	***3.3%***
	90% confidence range	[1.4%,3.5%]	[1.4%,2.8%]	[-11.3%,0.2%]	[-4.8%,0.4%]	[4.3%,9.1%]	-	-	*[1.2%,3.3%]*
	n	6	20	3	4	5	0	0	*38*
CCSE	estimate	**4.4%**	**1.1%**	**2.4%**	**3.9%**	**2.0%**	**1.9%**	**-**	***2.8%***
	90% confidence range	[1.3%,4.4%]	[0.2%,1.1%]	[0.7%,2.4%]	[1.8%,3.9%]	[0.6%,2.0%]	[0.3%,1.9%]	-	*[1.8%,2.8%]*
	n	4	10	16	37	21	11	0	*99*
ALL PAs	*estimate*	**2.2%**	**2.4%**	**4.2%**	**3.2%**	**2.2%**	**3.3%**	**1.2%**	***3.0%***
	90% confidence range	*[1.3%,2.2%]*	*[1.7%,2.4%]*	*[2.1%,4.2%]*	*[2.0%,3.2%]*	*[0.8%,2.2%]*	*[1.7%,3.3%]*	*[0.2%,1.2%]*	*[2.4%,3.0%]*
	n	*32*	*82*	*89*	*79*	*57*	*39*	*11*	*389*

Table 7 summarizes this information by PA and by system size. At the 90% confidence level, there are statistically significant differences between all three system size ranges: up to 100 kW; 100 kW to 500 kW; and 500kW and larger. More specifically, there is a decrease in the percentage of all midday hours with zero/near-zero output from 3.7 percent for small systems to 1.4 percent for large systems: small systems spend twice as much time as large systems not producing any power at midday.

The implications of these results are unclear: larger systems typically have multiple inverters; this approach would not identify an hour as zero/near-zero if some inverters in a system tripped and others did not. Given the large variation in output, it may not be possible to reliably identify step changes in output characteristic of single inverter trip at a multiple inverter site.

Table 7. Percentage of midday hours for which data is zero or near zero, by PA and system size

PA	≤ 100 kW	100 to 500 kW	≥ 500 kW	*All Sizes*
PG&E	***3.0%*** *[1.8%,3.0%]* *74*	***2.4%*** *[1.6%,2.4%]* *89*	***1.2%*** *[0.4%,1.2%]* *23*	***2.5%*** *[1.9%,2.5%]* *186*
SCE	***6.1%*** *[2.0%,6.1%]* *43*	***1.7%*** *[1.1%,1.7%]* *20*	***1.4%*** *[-0.9%,1.4%]* *3*	***4.6%*** *[1.9%,4.6%]* *66*
SCG	***4.1%*** *[0.3%,4.1%]* *20*	***2.3%*** *[0.8%,2.3%]* *16*	***2.8%*** *[-1.8%,2.8%]* *2*	***3.3%*** *[1.2%,3.3%]* *38*
CCSE	***2.6%*** *[1.2%,2.6%]* *53*	***3.0%*** *[1.8%,3.0%]* *42*	***2.4%*** *[-1.0%,2.4%]* *4*	***2.8%*** *[1.8%,2.8%]* *99*
ALL PAs	***3.7%*** *[2.5%,3.7%]* *190*	***2.4%*** *[1.9%,2.4%]* *167*	***1.4%*** *[0.7%,1.4%]* *32*	***3.0%*** *[2.4%,3.0%]* *389*

2.5.3 Missing Data

Table 8 summarizes the average percentage of daylight hours for which no output data was provided. On average, 19% of output data for daylight hours is missing. This missing data varies significantly by PA, from five percent (CCSE) to 43 percent (SCG), with significant reductions in missing data from earlier systems (27 percent to 36 percent missing for systems installed in 2002 to 2004) to later systems (one percent to ten percent for systems installed in 2005 onward). Missing data may be the result of data acquisition system failure, data acquisition service termination,[8] or data acquisition response to zero output.[9]

Table 8. Percentage of daylight hours for which data is missing, by PA and system's first year of operation

PA		2002	2003	2004	2005	2006	2007	2008	*ALL Years*
PG&E	estimate	**19%**	**37%**	**19%**	**8%**	**6%**	**2%**	**10%**	***16%***
	90% confidence range	[6%,33%]	[28%,46%]	[11%,26%]	[4%,12%]	[3%,8%]	[1%,3%]	[3%,18%]	*[13%,19%]*
	n	n = 18	n = 38	n = 39	n = 27	n = 25	n = 28	n = 11	*n = 186*
SCE	estimate	**47%**	**22%**	**48%**	**19%**	**26%**			***36%***
	90% confidence range	[33%,60%]	[7%,37%]	[39%,57%]	[9%,30%]	[-1%,52%]			*[29%,42%]*
	n	n = 4	n = 14	n = 31	n = 11	n = 6	n = 0	n = 0	*n = 66*
SCG	estimate	**58%**	**60%**	**3%**	**20%**	**3%**			***43%***
	90% confidence range	[33%,84%]	[45%,74%]	[-2%,9%]	[-13%,54%]	[-2%,8%]			*[32%,54%]*
	n	n = 6	n = 20	n = 3	n = 4	n = 5	n = 0	n = 0	*n = 38*
CCSE	estimate	**3%**	**3%**	**8%**	**6%**	**10%**	**0%**		***5%***
	90% confidence range	[3%,3%]	[3%,4%]	[4%,13%]	[5%,6%]	[3%,16%]	[0%,0%]		*[4%,7%]*
	n	n = 4	n = 10	n = 16	n = 37	n = 21	n = 11	n = 0	*n = 110*
ALL PAs	*estimate*	***29%***	***36%***	***27%***	***9%***	***9%***	***1%***	***10%***	***19%***
	90% confidence range	*[18%,39%]*	*[29%,43%]*	*[21%,32%]*	*[6%,12%]*	*[5%,13%]*	*[0%,2%]*	*[3%,18%]*	*[17%,21%]*
	n	*n = 32*	*n = 82*	*n = 88*	*n = 79*	*n = 57*	*n = 39*	*n = 11*	*n = 389*

2.6 *Normalizing Output Data by Weather and By First Year Output*

A measure of annual system output was necessary for this analysis. Measuring output was complicated by data gaps, which were inconsistent across sites. It was desirable to separate the performance of the system when it appeared to be operating normally from the performance of the system when it did not appear to be operating at all. Therefore, the *system performance* metric was developed to consider only those daylight hours of the year for which output appeared to be normal, i.e., not missing and not zero/near-zero. Annual system performance was defined as the ratio of annual system output during normal hours of the year to annual solar insolation.

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[8] Site data for one participant that we interviewed had missing data from mid-2006 onward; this correlated exactly with the timing of their online tracking service company terminating their service.

[9] Data for some of the systems reviewed had gaps for all non-daylight hours, suggesting that gaps for daylight hours might be zero-output hours.

$$SystemPerformance_{s,y} = \frac{\sum_{AllNormalHoursOfYear} Output_{s,h}}{\sum_{AllNormalHoursOfYear} Insolation_{s,h}}$$

Where:

- » $SystemPerformance_{s,y}$ is the system performance for site *s* in year *y*.
- » *AllNormalHoursOfYear* is the set of all hours of year *y* for which the output data for site *s* is present and greater than 0.5 percent of the system rated capacity.
- » $Output_{s,h}$ is the system output (kWh) at site *s*, in hour *h* of year *y*.
- » $Insolation_{s,h}$ is the solar insolation (Ly) at the nearest geographically appropriate weather station to site *s*, in hour *h* of year *y*.

System performance was only calculated for sites and years with at least 2,000 hours of normal output data (slightly less than half of the annual daylight hours).

In order to examine performance degradation specifically, a *normalized annual system performance* metric was also developed. This was defined as the ratio of system performance for a given year to system performance for the first calendar year of operation with at least 2,000 hours of normal output data:

$$NormalizedSystemPerformance_{s,y} = \frac{SystemPerformance_{s,y}}{SystemPerformance_{s,FirstYear}}$$

- » $NormalizedSystemPeformance_{s,y}$ is the normalized system performance of site *s*, in year *y*, relative to the first year system performance at site *s*.
- » *FirstYear* is the first calendar year of operation at site *s* for which there is at least 2,000 hours of normal data.

Section 3. Year-Over-Year Trends

Year-over-year performance and data character were examined for each system to identify trends in output during normal operation and in proportions of zero/near-zero, and missing data. These trends can be used to infer PV system performance and data acquisition performance.

The following tables summarize year-over-year data trends for system output during normal hours, midday hours of zero/near-zero output, and missing data. Trends are highlighted in green where they are statistically significantly different from zero with 90 percent confidence. The first row of each cell states the trend; the second row states the 90 percent confidence interval; the third row shows the number of sites upon which the result is based.

The aggregation of trends in performance during normal hours and in the portion of zero/near-zero hours provide the total trend in system output.

Where trends are significant, further analysis may be warranted to determine whether trends are mostly linear (assumed in this analysis) or non-linear (e.g. slope increasing or decreasing overtime, “shelf” or “plateau” characteristics).

3.1 Performance During Normal Data Hours

Table 9 summarizes the year-over-year trends in normalized system performance during daylight hours of normal data[10]. The average over all systems is a 0.8 percent decline, year-over-year, from the initial year of output. Trends that are statistically significantly non-zero are highlighted in green. Note that all statistically significant normalized performance trends in the table are negative, which implies that system performance does not improve over time and validates the use of this metric to examine performance degradation.

No statistically significant decline in performance of systems administered by SCE and SCG was observed. This is most likely because of the smaller number of systems administered by

[10] The overall number of sites is less in the performance results than in the data character results: performance results were only used if there were at least 2,000 hours of normal data per year.

these two PAs (and thus more difficult to observe small, statistically significant trends) and the smaller percentage of normal data hours (see Table 5), rather than an actual difference in performance between systems administered by these PAs and those administered by PG&E or CCSE.

Table 9. Year-over-year normalized performance trends, based on normal hours data

PA		2002	2003	2004	2005	2006	2007	*ALL Years*
PG&E	estimate	**-1.3%**	**-1.2%**	**-0.9%**	**-1.4%**	**-3.4%**	**-0.5%**	***-0.9%***
	90% confidence range	[-2.5%,-0.1%]	[-2.5%,0.1%]	[-1.9%,0.2%]	[-2.5%,-0.4%]	[-5.5%,-1.3%]	[-2.4%,1.4%]	*[-1.3%,-0.4%]*
	n	66	122	123	69	40	31	*459*
SCE	estimate	**-8.0%**	**-1.7%**	**3.7%**	**0.1%**	**-0.5%**	**-**	***-1.0%***
	90% confidence range	[-18.7%,2.7%]	[-4.1%,0.7%]	[-3.5%,11.0%]	[-3.8%,4.0%]	[-7.3%,6.3%]	-	*[-3.5%,1.4%]*
	n	9	49	39	15	7	0	*119*
SCG	estimate	**2.6%**	**-0.8%**	**-2.8%**	**-**	**3.6%**	**-**	***-0.4%***
	90% confidence range	[0.0%,5.3%]	[-2.2%,0.5%]	[-5.9%,0.2%]	-	[-1.9%,9.1%]	-	*[-1.5%,0.7%]*
	n	12	36	14	0	5	0	*67*
CCSE	estimate	**-3.0%**	**-0.7%**	**-0.3%**	**-0.4%**	**2.3%**	**12.4%**	***-1.1%***
	90% confidence range	[-4.4%,-1.6%]	[-1.8%,0.4%]	[-1.6%,1.1%]	[-1.2%,0.3%]	[-5.6%,10.1%]	[-10.8%,35.7%]	*[-1.8%,-0.4%]*
	n	24	54	70	128	40	16	*332*
ALL PAs	*estimate*	***-1.3%***	***-1.1%***	***-0.2%***	***-0.6%***	***0.0%***	***3.4%***	***-0.8%***
	90% confidence range	*[-2.4%,-0.2%]*	*[-1.8%,-0.3%]*	*[-1.5%,1.1%]*	*[-1.3%,0.0%]*	*[-3.9%,3.9%]*	*[-5.8%,12.6%]*	*[-1.3%,-0.4%]*
	n	*111*	*261*	*246*	*212*	*92*	*47*	*977*

Statisticall signifcantly non-zero trends are highlighted in green.
n *is the number of site-years, not the number of sites. For example, five years of data for a single site would count as five datapoints.*

Table 10 summarizes these results by system size. Although some individual results are statically significant, there are no statistically significant difference between system sizes is seen.

Table 10. Year-over-year normalized performance trends by system size, based on normal hours data

PA	≤ 100 kW	*100 to 500 kW*	≥ 500 kW	*All Sizes*
PG&E	***-1.2%*** *[-2.0%,-0.5%]* *200*	***-0.4%*** *[-0.9%,0.1%]* *205*	***-0.7%*** *[-2.8%,1.5%]* *54*	***-0.9%*** *[-1.3%,-0.4%]* *459*
SCE	***-2.0%*** *[-4.1%,0.0%]* *69*	***0.5%*** *[-5.4%,6.4%]* *42*	***6.5%*** *[-0.5%,13.5%]* *8*	***-1.0%*** *[-3.5%,1.4%]* *119*
SCG	***2.5%*** *[0.2%,4.7%]* *14*	***-1.9%*** *[-3.1%,-0.6%]* *46*	***3.2%*** *[-0.3%,6.7%]* *7*	***-0.4%*** *[-1.5%,0.7%]* *67*
CCSE	***-0.9%*** *[-1.7%,0.0%]* *197*	***-1.3%*** *[-2.9%,0.2%]* *120*	***-2.4%*** *[-4.7%,-0.1%]* *15*	***-1.1%*** *[-1.8%,-0.4%]* *332*
ALL PAs	***-1.1%*** *[-1.6%,-0.5%]* *480*	***-0.5%*** *[-1.3%,0.3%]* *413*	***-0.7%*** *[-2.2%,0.8%]* *84*	***-0.8%*** *[-1.3%,-0.4%]* *977*

3.2 *Fraction of Zero/Near-zero Data Hours*

Table 11 summarizes the year-over-year trend in annual hours of zero/near-zero output data[11]. On average, the amount of zero/near-zero data increases by 0.4 percent of all daytime hours, per year. This trend is relatively small in magnitude and only observable in aggregate and for some installation years for systems administered by PG&E.

Table 11. Year-over-year trend in proportion of daylight hours with zero/near-zero output data

PA		2002	2003	2004	2005	2006	2007	*ALL Years*
PG&E	**estimate**	**0.3%**	**0.6%**	**0.6%**	**1.3%**	**-0.8%**	**2.9%**	***0.4%***
	90% confidence range	[0.0%,0.6%]	[0.1%,1.2%]	[0.2%,1.0%]	[-0.1%,2.8%]	[-1.5%,-0.1%]	[-0.2%,6.0%]	*[0.2%,0.6%]*
	n	80	156	147	84	46	43	*567*
SCE	**estimate**	**0.0%**	**0.0%**	**3.0%**	**0.4%**	**0.2%**	**-**	***0.9%***
	90% confidence range	[-0.3%,0.4%]	[-1.1%,1.1%]	[0.6%,5.3%]	[-0.7%,1.5%]	[-1.0%,1.4%]	-	*[-0.1%,2.0%]*
	n	19	63	99	28	11	0	*220*
SCG	**estimate**	**-0.4%**	**0.2%**	**0.1%**	**-**	**-**	**-**	***0.0%***
	90% confidence range	[-1.4%,0.6%]	[-0.3%,0.7%]	[0.0%,0.1%]	[-1.0%,0.4%]	[-8.1%,19.4%]	-	*[-0.4%,0.5%]*
	n	20	63	14	6	8	0	*111*
CCSE	**estimate**	**2.3%**	**0.1%**	**0.4%**	**-0.9%**	**-1.5%**	**-0.8%**	***0.0%***
	90% confidence range	[-0.1%,4.6%]	[-0.3%,0.5%]	[-0.6%,1.5%]	[-2.3%,0.4%]	[-3.2%,0.1%]	[0.0%,0.0%]	*[-0.5%,0.5%]*
	n	24	60	75	145	56	21	*381*
ALL PAs	***estimate***	***0.4%***	***0.3%***	***1.3%***	***-0.2%***	***-0.7%***	***1.7%***	***0.4%***
	90% confidence range	*[-0.1%,0.8%]*	*[0.0%,0.7%]*	*[0.5%,2.1%]*	*[-1.1%,0.7%]*	*[-1.8%,0.5%]*	*[-0.5%,3.9%]*	*[0.1%,0.6%]*
	n	*143*	*342*	*335*	*263*	*121*	*64*	*1279*

Statistically signifcantly non-zero trends are highlighted in green.
n *is the number of site-years, not the number of sites. For example, five years of data for a single site would count as five datapoints.*
" - " indicates too little data to determine this statistic

Table 12 summarizes this information by system size. A statistically significant difference is seen between system between 100 and 500 kW (0.1 percentage points annually) and larger systems (1.0 percentage points annually).

[11] These results do not include missing data: the fraction of zero/near-zero hours is the ratio of the number of zero-near-zero hours to the sum of all hours for which data was provided.

Table 12. Year-over-year trend in proportion of daylight hours with zero/near-zero output data, by system size

PA	≤ 100 kW	100 to 500 kW	≥ 500 kW	*All Sizes*
PG&E	***0.5%*** *[0.2%,0.9%]* *254*	***0.3%*** *[-0.1%,0.7%]* *250*	***0.2%*** *[-0.1%,0.6%]* *63*	***0.4%*** *[0.2%,0.6%]* *567*
SCE	***1.2%*** *[-0.4%,2.7%]* *150*	***0.0%*** *[-0.4%,0.4%]* *60*	***0.2%*** *[-1.6%,2.0%]* *10*	***0.9%*** *[-0.1%,2.0%]* *220*
SCG	***0.1%*** *[-0.8%,1.1%]* *41*	***0.1%*** *[-0.5%,0.6%]* *62*	***-1.2%*** *[-3.1%,0.6%]* *8*	***0.0%*** *[-0.4%,0.5%]* *111*
CCSE	***-0.2%*** *[-0.9%,0.5%]* *220*	***-0.3%*** *[-1.0%,0.4%]* *145*	***3.5%*** *[0.9%,6.2%]* *16*	***0.0%*** *[-0.5%,0.5%]* *381*
ALL PAs	***0.4%*** *[0.0%,0.9%]* *665*	***0.1%*** *[-0.2%,0.3%]* *517*	***1.0%*** *[0.4%,1.6%]* *97*	***0.4%*** *[0.1%,0.6%]* *1279*

3.3 *Fraction of Missing Data Hours*

Table 13 summarizes the year-over-year trend in annual hours of missing output data. On average, the amount of zero/non-zero data increases by 5.7 percent of daylight hours, per year. This increase in missing data is most significant (6.3 percent to 7.8 percent) for systems installed in 2002 through 2004. This decline is not observed in CCSE administered systems and ranges from 7.3 percent to 10.5 percent in systems administered by the other PAs. This differentiation suggests that there are differences in how PAs collect performance data and CCSE data acquisition practices should be examined and exemplified. Such high decreases in available data, year-over-year, at the other PAs compromise the ability to accurately assess performance and identify performance trends.

Table 13. Year-over-year trend in proportion of daylight hours with missing output data

PA		2002	2003	2004	2005	2006	2007	*ALL Years*
PG&E	**estimate**	**2.6%**	**10.3%**	**5.7%**	**3.3%**	**1.4%**	**-0.2%**	***7.3%***
	90% confidence range	[-0.9%,6.1%]	[7.5%,13.1%]	[2.7%,8.8%]	[0.3%,6.4%]	[-2.2%,4.9%]	[-2.0%,1.5%]	*[6.0%,8.6%]*
	n	92	206	170	85	46	43	*653*
SCE	**estimate**	**16.0%**	**4.2%**	**12.2%**	**6.4%**	**14.3%**	-	***8.0%***
	90% confidence range	[11.2%,20.9%]	[-0.4%,8.7%]	[7.8%,16.6%]	[-2.3%,15.2%]	[-12.7%,41.2%]	-	*[5.3%,10.7%]*
	n	22	72	124	29	13	0	*260*
SCG	**estimate**	**13.5%**	**9.8%**	**-1.8%**	**-10.0%**	**-13.2%**	-	***10.5%***
	90% confidence range	[7.2%,19.7%]	[5.9%,13.8%]	[-5.3%,1.6%]	[-36.6%,16.6%]	[-18.2%,-8.2%]	-	*[7.4%,13.6%]*
	n	37	115	14	7	8	0	*181*
CCSE	**estimate**	**0.5%**	**0.5%**	**2.7%**	**-2.2%**	**-0.2%**	**-0.1%**	***0.0%***
	90% confidence range	[-0.9%,2.0%]	[-0.3%,1.4%]	[0.0%,5.3%]	[-3.2%,-1.1%]	[-7.0%,6.7%]	[-0.8%,0.5%]	*[-0.9%,0.8%]*
	n	24	60	78	145	60	21	*388*
ALL PAs	**estimate**	**6.3%**	**7.8%**	**7.6%**	**0.9%**	**0.7%**	**0.0%**	***5.7%***
	90% confidence range	*[3.5%,9.0%]*	*[5.9%,9.8%]*	*[5.4%,9.8%]*	*[-0.9%,2.6%]*	*[-3.8%,5.2%]*	*[-1.2%,1.2%]*	*[4.9%,6.5%]*
	n	*175*	*453*	*386*	*266*	*127*	*64*	*1482*

Statistically signifcantly non-zero trends are highlighted in green.
n *is the number of site-years, not the number of sites. For example, five years of data for a single site would count as five datapoints.*

This topic was discussed with Itron to understand the reasons for the magnitude of these trends and the differences across PA and across installation year. There are many modes of failure that can result in missing data, including data acquisition system installation, data acquisition system equipment failure, communication system failure/termination, and data retrieval/storage failure. Data acquisition system equipment, installers, and maintainers have not been consistent across years or PAs, making an analysis of factors influencing trends in missing data impossible for this study.

The objective of this study was to characterize PV performance degradation and identify the causes for this degradation; the magnitude of missing data does not impact performance degradation findings; however, to the extent that it reduces the pool of available data, missing data does limit the ability to draw statistically significant conclusions, particularly on subsets of the population.

Section 4. Participant Interviews

Participant interviews were conducted with a sample of 35 of the PV sites for which performance data was provided. The objectives of these interviews were to 1) correlate data gaps and strings of zero/near-zero output data to participant experience and 2) collect qualitative information on system performance and factors affecting system performance.

4.1 Sample Selection

The interview sample was designed to span the four PAs and the range of observed data character and performance. Only sites with three or more years of data were considered; otherwise, there were no trends to observe.

Sites were ranked on four criteria:

» Zero/near-zero output data time a percentage of all normal and zero/near-zero hours.

» Standard deviation of annual performance.

» Correlation of annual performance to system age.

» The product of [1- correlation] and the standard deviation of output score: this identified sites with high standard deviation but little net movement, implying significant annual variation, but on average, no change.

Sites were then selected to ensure a range of rankings on these four criteria, across all four PAs. A total of 80 sites were selected. Each site was contacted several times; a total of 35 sites were ultimately interviewed.

Because of the non-random sample selection, these results are not necessarily representative of the population of SGIP PV systems. However, in keeping with the objective of this performance degradation examination, these interview results describe the host experience for those sites with the most significant deviation from "normal" output.

4.2 Interview Topics

Interview subjects were asked to describe their systems and the performance of their systems. They were then asked specifically about extended (more than one day) periods of zero/near-zero data and missing data that we had observed in their output data.

Subjects were also asked:

- » Where the system is located.
- » What type of building/business at which the system is located.
- » How many employees there are at the site.
- » Who owns the equipment.
- » Who is in charge of equipment maintenance.
- » If they have a maintenance contract (and what it covers).
- » To describe any system outages (e.g., inverter, panel, connection problems).
- » To describe any shading and any changes in shading over time.
- » How frequently they clean their panels.
- » How dirty the panels are when they get cleaned.
- » Any modifications made to the system.

The full interview guide is provided in *Appendix A: Interview Guide*.

The following subsections describe the findings from these interviews. The sample size was too small to identify significant differences across PAs; results are therefore not disaggregated by PA.

4.3 Participant Monitoring of Systems

About one quarter (9 respondents) of the 35 respondents carefully monitor their system's performance (Figure 2). These respondents included some large public entities, such as universities and municipalities with strong environmental initiatives and an informed staff or other resources in place (e.g., students) to conduct monitoring activities. However, the respondents with detailed system monitoring in place included a mix of entities: public and private, as well as large and small organizations. Many of these respondents cited their use of an advanced data acquisition system with a display that facilitates ongoing performance monitoring. In most cases, the respondents were informed about the details of their PV system and were "champions" for the system, committed to the success of the PV investment.

Nearly half of all respondents (16 respondents, 46 percent) were monitoring their system's performance at a low level of detail. Many of these respondents cited a monitoring system that their PV system installer had provided and noted that their installer contacted them when there was a problem with the system. These respondents tended to have a general understanding of how their system was functioning, and when major outages had occurred, but they were not attuned to fluctuations in performance.

Nearly 30 percent of respondents (ten respondents) were completely disengaged from any system performance monitoring activities.

Figure 2 summarizes the reported levels of system monitoring.

Figure 2. Level of participant monitoring of system performance

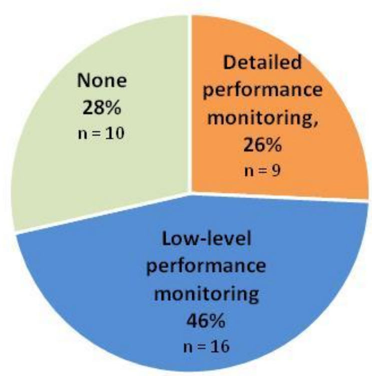
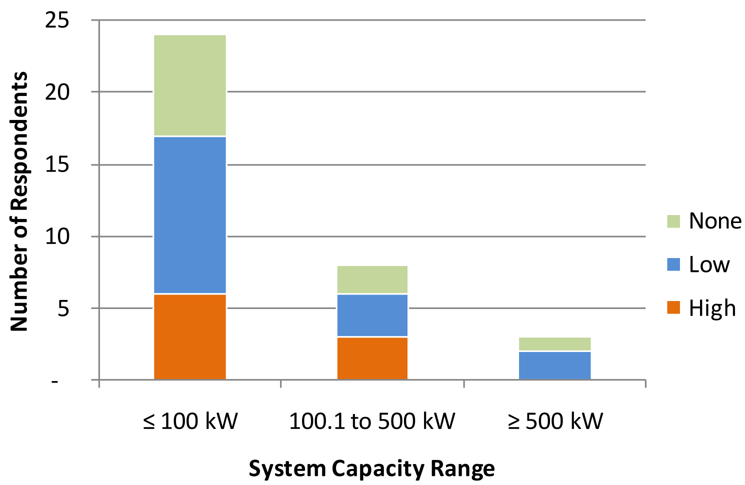


Figure 3 summarizes these results by system size. The relatively small sample size of interview respondents makes it unclear if significant differences in the character or frequency of inverter issues is correlated to system size.

Figure 3. Level of participant monitoring of system performance, by system size



Those respondents with little or no system monitoring activity underway tended to be from organizations where there had been a turnover of staff responsible for maintaining the system, and/or where there appeared to be a low level of commitment to the success of the PV system investment on the part of the person responsible for system maintenance. A number of these respondents noted that they had experienced technical difficulties with the data acquisition or monitoring system that had been installed upon initial system installation. In some cases, the installer had stopped maintaining software; in other cases the data acquisition and monitoring services were discontinued at end of warranty and the respondent did not want to pay a monthly fee for continuation of that service.[12]

Among the 29 respondents for which program data indicated there had been significant zero/near-zero periods and/or data gaps, slightly more than half (52 percent, or 15 respondents) were unable to corroborate the program records regarding outages at their site. Forty eight percent of respondents from sites where program records indicate significant outages have occurred were able to recall some of these events; however, few could recall all of the events

[12] For example, one host site discontinued a $30/month service that provided online monitoring capabilities.

observed in the data. In most cases, the respondents did not recall the specific outages until prompted by the interviewer.

An examination of the correlation between system performance and extent of monitoring (high, low, none) was conducted. The three performance metrics considered were the percent of midday hours with zero/near-zero output (an estimate of total potential output lost to outages) (Figure 4) , annual percentage point trend in midday hours with zero/near-zero output (Figure 5), and annual percentage point trend in performance (relative to first year performance) during normal hours (Figure 6).

In these figures, the gray boxes represent that 90% confidence interval of the estimated average for the population, and the green and red bars represent the lower and upper values in the range of values in the sample. Note that there is no statistically significant difference in values as a function of monitoring extent for any of these metrics. This is not surprising, given the relatively small sample sizes (approximately 10 respondents per group). Recall that the interviewed sample selection was baised towards sites with observable changes: these results should not be considered representative of the entire SGIP PV system population.

Figure 4. Percent of midday hours with zero/near-zero output, by extent of system monitoring

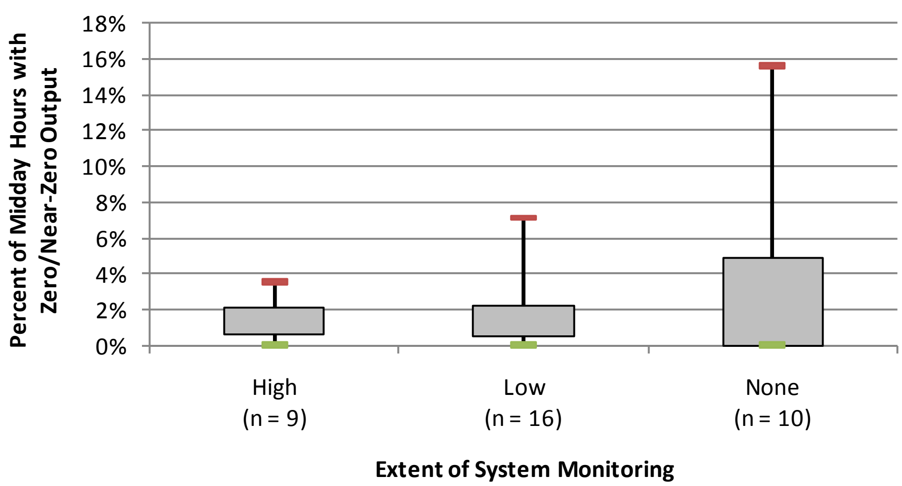


Figure 5. Annual percentage point trend in percent of midday hours with zero/near-zero output, by extent of system monitoring

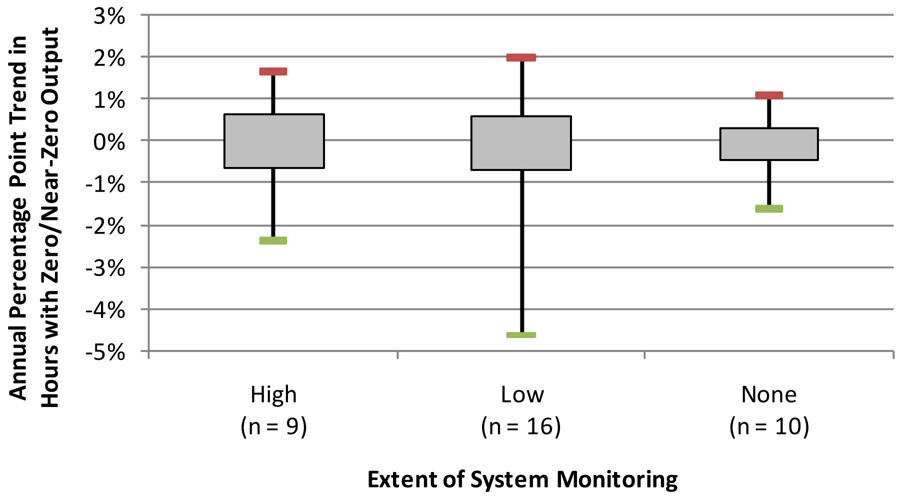
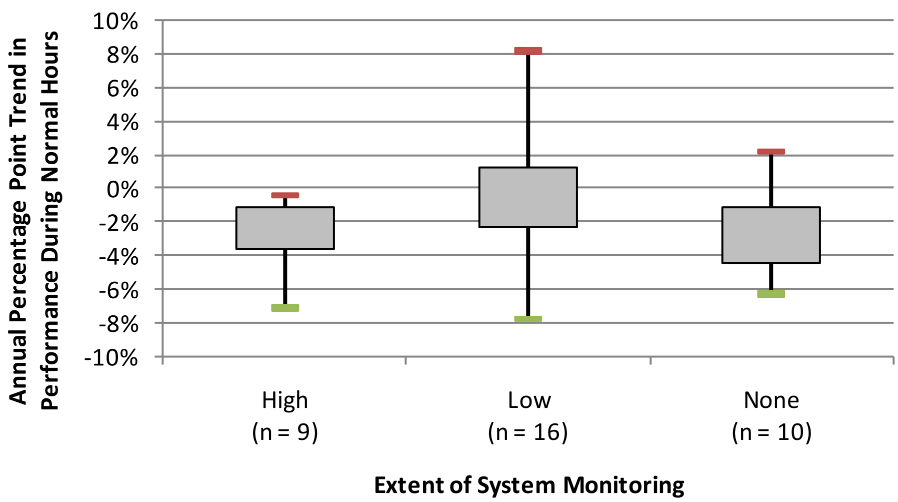


Figure 6. Annual percentage point trend in performance during normal hours, by extent of system monitoring



4.4 *Factors Affecting System Performance*

Equipment failures, dirt and dust accumulation, shade from growth of nearby vegetation, poor system engineering, and gradual degradation of PV modules' capacity factor with age are all potential contributors to a decline in PV system performance in any part of the country. Another factor of particular significance in California is the presence of fog and salt accumulation on systems in coastal locations. Respondents reported experiencing the effects of all of these performance factors to some degree. Equipment failures, dust and dirt accumulation, and coastal fog and salt accumulation were the most frequently reported factors. Shading was also reported by several respondents, but in most cases the shading existed at the time of installation; it was not due to lack of pruning.

Wildfires were also cited as a relatively infrequent, though significant source of debris that has driven the need to conduct major cleaning activity in some locations. One respondent noted that grass had started growing on some rooftop modules following a fire which had deposited significant debris, and subsequent moisture collection.

4.5 *Cleaning Practices*

Nearly all respondents recognized that accumulation of dust, dirt and other debris causes a decline in system performance. Most respondents also acknowledged the importance of cleaning PV modules to maintain system performance. Some respondents noted that the location of their PV system makes regular cleaning particularly important (i.e., those located near areas with heavy machinery in use, locations with farming and livestock activity, and areas along the coast where a salt residue accumulates). One respondent whose system is located near a construction zone notices a decline in performance of approximately ten percent when modules are dirty.

For nearly 70 percent of respondents, cleaning of PV modules is done by in-house staff, generally the facilities maintenance staff. 17 percent of respondents (six respondents) hire a third party to clean their PV modules, and 14 percent of respondents (five respondents) do not clean their PV modules at all. Among those who outsource cleaning services, about half receive the service as part of a broader PV system maintenance contract. Two respondents hire a window washing company to clean their modules.

Most respondents clean their modules either quarterly (23 percent, eight respondents) or annually (20 percent, seven respondents). Other respondents clean their modules monthly (nine percent, three respondents), twice a year (14 percent, five respondents), not at all (14 percent, five respondents), or on some other schedule (20 percent, seven respondents). A few respondents noted that it's unnecessary to clean the system during the more rainy winter months, but that they clean the system on a near-monthly basis during the drier summer months.

Hosing modules off with tap water is a common cleaning method. Others use brushes or cloths to remove debris from the modules. A few respondents cited use of automated sprinklers for cleaning purposes. One respondent noted the importance of using de-ionized water to avoid residue from detergents that could attract dirt, as well as mineral build-up that might result from use of tap water.

Several respondents commented that their staff is either unqualified or unavailable to clean modules. A few respondents cited the expense of hiring outside resources to clean and maintain systems as a significant burden.

Figure 9 and Figure 10 summarize the breakdown of who cleans panels and how frequently panels are cleaned.

Figure 7. Respondent identification of who cleans panels

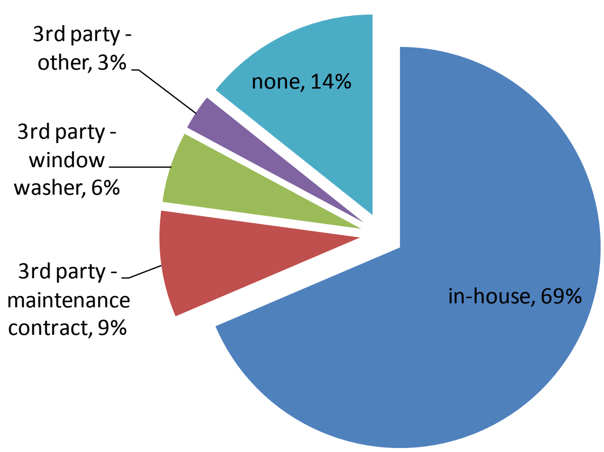
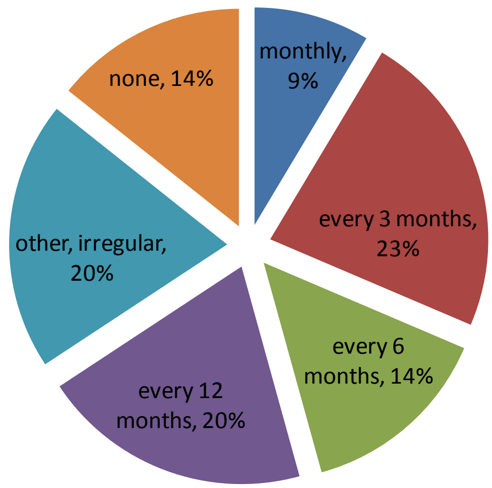


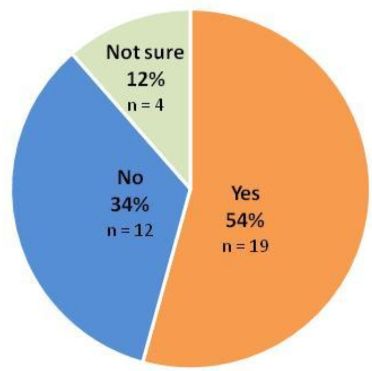
Figure 8. Respondent identification panel cleaning frequency



4.6 *Inverter Performance*

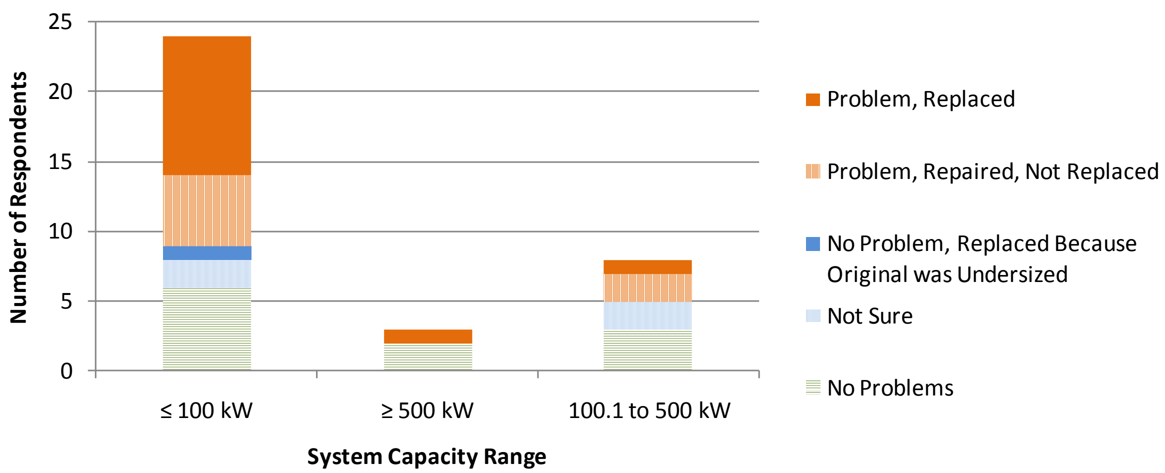
As shown in Figure 9, the majority of respondents experienced some form of technical difficulty with their inverters. In many cases, this was a matter of the inverter tripping for some unknown reason (e.g., a blown fuse, temperature, or wiring problem). 37 percent of respondents reported that at least one inverter had been replaced, most during the initial warranty period, which typically extends for five years from the date of installation. In other cases, installers would explain to a maintenance person over the phone how to "awaken" a tripped inverter. Clearly, inverter maintenance and repair is a key issue requiring attention as a PV system ages. Furthermore, inverter replacement can represent a significant expense after a warranty expires if no follow-on maintenance contract is secured.

Figure 9. Respondents experiencing technical problems with inverters



The prevalence of inverter issues by system size was also examined (Figure 10), although the relatively small sample size of interview respondents makes it unclear if significant differences in the character or frequency of inverter issues is correlated to system size.

Figure 10. Respondents experiencing technical problems with inverters, by system size



4.7 Module Performance

PV modules appear much more reliable than do inverters. Twenty three percent of respondents (eight respondents) reported dramatic problems with module performance resulting in replacement under warranty.

PV modules are expected to last much longer than inverters, which accounts for some of the disparity between the inverter and module reliability findings. Inverter manufacturers typically offer a five-year warranty, whereas module manufacturers often offer a 25-year warranty.

It is also possible that poor module performance is less easily detected than poor inverter performance, depending on system configuration and wiring. If a module's output is ten percent less than expected, or if one module stops functioning but the rest of the system is still producing power, the defect could easily go unnoticed. In contrast, a failed inverter is more likely to bring down an entire system and be more easily detected.

Lack of detection of under-performing modules is much more likely in cases where the site host owns the equipment (as opposed to a third-party ownership arrangement) and where there is no system performance guarantee that is actively monitored and enforced. Only one respondent reported that their system was leased or owned by an entity other than the site host.

4.8 Additional Findings

Additional findings emerging from interviews with PV system contacts include the following:

» When warranties expire, improper attention to maintenance is a strong possibility. A few of the more sophisticated respondents are entering into maintenance contracts after their warranties expire, but this is a minority of respondents.

» Contracts are hard to enforce and equipment failures can easily go undetected (meaning warranty terms would never by enforced). Many respondents had inverters replaced under warranty, but a similar number had little formal monitoring and were uncertain about systems' performance. In these cases, it is possible that faulty equipment went undetected. One respondent explained that he had a performance guarantee and maintenance contract with his installer, but the installer had stopped honoring the terms of the agreement, and then was bought out by another company that also failed to follow through on the performance guarantee.

- Project owners typically rely on the original system installer to conduct repairs and maintenance.

- The relationship a site host has with an installer seems to have strong bearing on how well a system is monitored / maintained over time.

- A number of respondents were not familiar enough with the system components / configuration to be able to understand system performance issues.

- Some unique maintenance requirements can arise due to poor system configuration and design. One respondent noted that panels were located so close together on a roof with vegetation growth that weeding had become a maintenance hassle. There was not enough room between modules to weed effectively.[13]

- Only one respondent noted that there had been a roof leak as a result of the respondent's PV system installation.

[13] Interestingly, this respondent also noted a problem with fire safety. Modules covered such a large percentage of the roof that the fire inspector required removal of some panels to ensure the roof could be penetrated in the event of a fire.

Section 5. Conclusions

This analysis sought to characterize the observed performance degradation in SGIP PV systems.

5.1 Findings

Based on the data available for metered systems, we observed that:

1) The most significant cause for the perceived decline in annual capacity factor with age (as noted in the SGIP Eighth-Year Impact Evaluation) is actually in *increase* in capacity factor of newer systems, relative to earlier systems; the year-over-year trend a given systems performance is much more stable.

Table 14 summarizes the average capacity factor by first year of operation and system age. The blue bars indicate the relative magnitudes of each value: the shortest bar represents a value of 0.131 and the longest bar represents a value of 0.193. The clear declining trend in capacity factor by age is seen in the bottom row of data, particularly for ages 4 through 6. However, the average values for systems of all ages (last column on the right) show that new system have higher capacity factors each year. The trend in capacity factor as those systems age (first seven rows of the table) is much less significant.

Table 14. Annual Capacity Factor by First Year of Operation and System Age

First Year of Operation	Age							
	0	1	2	3	4	5	6	All Ages
2002	0.131	0.162	0.157	0.149	0.145	0.157	0.138	0.152
2003	0.145	0.161	0.157	0.153	0.164	0.154		0.156
2004	0.165	0.166	0.160	0.170	0.157			0.164
2005	0.166	0.171	0.175	0.174				0.172
2006	0.168	0.191	0.189					0.185
2007	0.179	0.184						0.182
2008	0.193							0.193
All Years	0.164	0.171	0.168	0.165	0.157	0.155	0.138	0.165

2) The average performance of individual systems over time is reasonable.

Output during times when systems are online and producing power declines by 0.8 percent (relative to the first year of output) per year, after controlling for annual variation in solar insolation. This decline in system performance is on par with manufacturer claims (typically 20 percent degradation after 20 years) and observed performance from other studies.[14]

On average, systems are online and producing power 97 percent of daytime hours; this on-time decreases at a rate of 0.4% of all daylight hours, per year.

Table 15 summarizes these results.

[14] For example, a 2002 NREL study on this topic observed 0.7 percent degradation per year.

Osterwald, C.R. et al., *Degradation Analysis of Weathered Crystalline-Silicon PV Modules*, Proceedings of the 29th IEEE PV Specialists Conference, New Orleans, LA May 2002 and NREL document NREL/CP-520-31455. Pre-print available online via http://docs.google.com.

Table 15. Year-over-year trends in system performance, outages, and missing data

	Year-over-year percentage point trends		
PA	***Peformance during normal hours, relative to first year performance***	***Midday hours with zero/near-zero output, as a percentage of all midday hours***	***Missing data, as a percentage of all daytime hours***
PG&E	***-0.9%*** *[-1.3%,-0.4%]* *459*	***0.4%*** *[0.2%,0.6%]* *567*	***7.3%*** *[6.0%,8.6%]* *653*
SCE	***-1.0%*** *[-3.5%,1.4%]* *119*	***0.9%*** *[-0.1%,2.0%]* *220*	***8.0%*** *[5.3%,10.7%]* *260*
SCG	***-0.4%*** *[-1.5%,0.7%]* *67*	***0.0%*** *[-0.4%,0.5%]* *111*	***10.5%*** *[7.4%,13.6%]* *181*
CCSE	***-1.1%*** *[-1.8%,-0.4%]* *332*	***0.0%*** *[-0.5%,0.5%]* *381*	***0.0%*** *[-0.9%,0.8%]* *388*
ALL PAs	***-0.8%*** *[-1.3%,-0.4%]* *977*	***0.4%*** *[0.1%,0.6%]* *1279*	***5.7%*** *[4.9%,6.5%]* *1482*

3) **Nineteen percent of output data is missing, and the percentage of all hours for which data is available decreases by 5.7 percentage points per year.**

There were significant differences in the amount of missing data across PAs, ranging from five percent for CCSE to 16 percent for PG&E, to 36 percent for SCE, to 43 percent for SCG. Additionally, the amount of missing data is significantly less in systems installed in 2004 or later than in systems installed in 2002 and 2003. These significant differences across time and PA suggest that the amount of missing data can be minimized through data acquisition implementation best practices.

Missing data and increases in missing data limit the ability to draw conclusions about subsets of the population and as systems age.

4) For this sites with the most significant performance variation, interviews revealed a range of host attention to system, widespread and frequent cleaning, and significant system failures.

Most of interviewed participants are not closely monitoring their systems – Forty six percent of interviewed participants reported low levels of monitoring, and 28 percent reported no monitoring. As noted above, system performance and inverter performance does change over time; if these systems are not monitored, performance issues resulting in poor to no performance may persist.

Most systems are cleaned regularly – Eighty six percent of interviewed participants either clean their panels regularly or contract others to clean their panels regularly.

PV systems are error prone – The notion of "plug and play" systems with high reliability because of the absence of moving parts is not entirely accurate:

- **Inverters** – Fifty four percent of interviewed participants experienced problems with their inverter performance. 34 percent did not, and 12 percent were not sure.
- **Panels** – Twenty three percent of interviewed participants had their panels replaced (at no cost to them) due to panel performance issues.

5.2 Recommendations

The objective of this analysis was to characterize PV performance degradation and identify its causes. We found that performance degradation of individual systems is significantly less than that implied by the capacity factor versus age analysis provided in the eighth-year impact evaluation and that the performance degradation we did observe was reasonable. Two thirds of degradation is attributable to reductions in output during hours that the system is online and producing power. This is not a controllable cause of degradation.

The remaining one third of degradation is attributable to outages (periods of zero/near-zero data output). Performance gains could be achieved by reducing hours of zero/near-zero output by working with equipment manufacturers and installers to minimize equipment (panels and inverters) performance issues. However, as it is, systems are online and producing power 97% of the time. Even if attentive monitoring and maintenance were able to halve this outage time, this would only increase expected annual energy output of a system by 1.5 percent; this increased diligence may not prove to be cost-effective.

In the course of this analysis, the significant extent of missing data and the significant year-over-year increase in missing data stood out; that system administered by CCSE and systems installed in more recent years did not demonstrate these significant amounts of or trends in missing data suggest that high and increasing levels of missing data are not unavoidable. Further analysis is recommended to determine the data acquisition equipment and protocols applied to CCSE administered sites, as a benchmark for future SGIP and CSI data acquisition. The current data and data quality only allows for the most general statements of output and trends, particularly as systems age. High levels of data availability will be necessary to examine performance by subgroups, such as module type or installer.

5.3 Further Research

Several unanswered questions suggest further research:

What factors have led to the dramatic increase in capacity factor of newer systems? As seen in Table 14, capacity factor of systems installed in 2002 was 0.131 during the first year of operation. For systems installed in 2008, the average capacity factor was 0.193.

Are there observable performance differences by installer or equipment type and/or manufacturer? This level of detail was not possible within the scope of the analysis described in this report, but may be of interest. However, the results described here demonstrate a large variance in system performance, and drawing statistically significant conclusions about small subsets may be difficult.

To the extent that outages can be minimized by equipment specification and monitoring/response, how can program specifications optimize the cost-effectiveness of these actions? Possible program activities might include the specification of eligible system components (notably inverters) based on performance criteria and the requirement of maintenance contracts with specified response times to outages.

What data acquisition protocols could be adopted to minimize missing data? A starting point for this examination would be to compare data acquisition for CCSE administered systems to those of systems administered by the other PAs, given the significantly lower prevalence of missing data from CCSE administered systems. Missing data has been less significant in the most recent years, and this issue may be resolving itself.

Appendix A: Interview Guide

Introduction

Hello, my name is ____________________ and I work for Summit Blue Consulting. I am calling on behalf of the California Public Utilities Commission. We are conducting interviews to explore performance of Self-Generation Incentive Program systems. This interview is for research purposes only.

NOTE: IF RESPONDENT QUESTIONS THE LEGITIMACY OF THE SURVEY, YOU MAY GIVE THEM BETSY WILKINS' EMAIL ADDRESS. ALSO SEND BETSY AN EMAIL WITH THE NAME AND ORGANIZATION OF THE PERSON WHO MAY BE CONTACTING HER.

Betsy Wilkins

Consultant to the Pacific Gas & Electric Company

bawilkins@sbcglobal.net

Taping (optional)

With your permission, I'll record the interview to avoid slowing down our conversation by taking all written notes. I will not use the tapes for anything other than note taking and analysis. *(NOTE TO INTERVIEWER: Taping is optional, but you must obtain consent before doing so.)*

I. System Information

First I would like to obtain a few details about the installed self-generation system.

1. What technology did you install on-site? [*To confirm database records*]

    a. Solar PV
    b. Combined heat and power (CHP)/Cogeneration [*If CHP, use CHP guide*]
    c. Other____________ [*If other, thank respondent and terminate survey*]

2. What is the size of the system (capacity in kW or MW)? __________________ [*To confirm database records*]

3. Is the system tilted or flat?

a. **[If tilted]** What is the angle of tilt?

4. When was the system installed and operational (month/year)? ________________ [*To confirm database records*]

5. In what zip code is the system located? _____________[*To confirm database records*]

6. Where is the system located on-site? [*Prompt if needed, e.g., on roof, on carport, on ground*]

7. Please describe the area surrounding the system. [*Prompt if needed, e.g., surrounded by buildings, open space, wooded*]

8. Does the system receive any shading throughout the day/year?

   a. **[If yes]** Please elaborate.

9. **Has the amount of shading changed over time?**

   a. **[If yes] Please elaborate.**

10. Is the person that led the installation for your company still at the company/working on the system?

    a. **[If no]** Who now oversees the system?

II. System Operations

Now I would like to discuss the operation of your system.

11. Is the PV system still installed?

    a. **[If no]** When and why was it removed?

12. Is the system operational?

    a. **[If no]** When and why did it break?

    b. **[If no]** Does your company have plans to operate the system in the future?

13. Is the system capable of being operated, but not currently operating?

a. **[If no]** Why is it not operating?

14. **Has the system been inoperable for any periods of time?**

    a. **[If yes] What broke? When was this? How long was it broken for? Who was (financially) responsible for this maintenance?**

15. **[If operating]** Is the system operating at capacity?

    a. **[If no]** Why not?

16. **[If operating]** Does the system operate reliably?

    a. **[If no]** Please elaborate.

17. **[If operating]** How long do you expect that you will operate the system?

18. **[If ever operated]** Did the system have any start-up problems?

    a. **[If yes]** Please explain.

19. Would you have operated the system differently if rather than an up-front incentive, you were paid on a per kWh generated basis (a performance based incentive)?

    a. [**If yes**] Please explain.

20. How would the performance of this system affect your decision to install a PV system or to recommend someone else to install a PV system?

21. Do you have a performance monitoring system in place?

    a. **[If yes**] Please describe.

III. System Maintenance

Next I would like to discuss the maintenance of your system.

22. **[If operating]** Does the system require routine maintenance?

    a. **[If yes]** please describe.

    b. Do you perform or have someone else perform the maintenance?

    c. Are there situations when maintenance is needed but is not performed?

23. Is the system still under warranty?

    a. **[If no]** Does this affect the maintenance of the system?

24. Do you currently have a service plan with a service company? Have you had a service plan in the past?

25. Has any part of the system been replaced since initial operation, or has the unit required any repair?

    a. **[If yes]** Please describe.

    b. Was the repair or replacement done under warranty?

26. Have you had any inverter problems?

    a. **[If yes]** Please explain.

27. Have you had any panel or cell problems?

    a. **[If yes]** Please explain.

28. Do you notice dirt on the panels?

    a. **[If yes]** Please explain.

29. Do you clean your panels on a regular basis?

    a. **[If yes]** How frequently? What time(s) of year?

IV. System Design and Installation

Lastly, I would like to discuss the design and installation of the system.

30. Do you feel the system was well designed?

    a. **[If no]** Please explain.

31. Do you feel the system as manufactured was basically high quality?

    a. **[If no]** Please elaborate.

32. Do you feel the installation of the system was of high quality?

    a. **[If no]** Please elaborate.

33. Do you feel the system is properly sized for your facility?

    a. **[If no]** Please explain.