TECHNOLOGY TRIAL STUDY EVALUATION

Technical Memorandum

RST-Cleantech USA, LLC

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Contents

1 INTRODUCTION

RST-Cleantech USA, LLC (“RST” or the “Customer”) has requested DNV GL Energy USA, Inc., (hereinafter DNV GL), to provide an independent technical review of a pilot study conducted of the Customer’s proprietary cleaning solution for the mitigation of soiling caused by the deposition of dust and other substances onto the glass surface of photovoltaic (PV) modules.

According to the Customer, the solution achieves soiling mitigation through the spraying of water from custom nozzles mounted onto the metal frame along the top edge of tilted PV modules. The nozzles are designed with a 184-degree spray angle to ensure good water distribution across the lateral width of panels, allowing gravity to pull the water down and carry away light-blocking substances. For this pilot study, a washing event was programmed to occur only in the evening and utilizes approximately one (1) quart of filtered water per nozzle per wash. Polyethylene conduits carry water to the nozzles from an electrolysis filter that aims to remove minerals (such as calcium and magnesium) from the water, reducing potential fouling caused by hard water (see Figure 1-1 and Figure 1-2).

Figure 1-1: RST nozzle mounted on PV module frame (from Customer website)

Figure 1-2: water spraying from nozzle onto modules (from Customer website)

2 PILOT STUDY

In early 2020, the Customer commenced a pilot study of their PV module cleaning solution at a roof-mounted PV system ("Pilot System") at a facility located approximately 10 miles southwest of Los Angeles, California in the United States. The Pilot System has a total ac capacity of approximately 1.3 MW and comprises 14 PV inverters (one (1) inverter at 1 MW nameplate capacity and thirteen (13) at 23 kW capacity) connected to strings of multi-silicon modules installed on fixed-tilt racking. For the present study, only the thirteen inverters rated at 23 kWac were analyzed and compared.

The installation of the Customer's solution at the Pilot System—including the water filtration system, the conduits and nozzles, as well as the flow controls equipment—occurred between January 29, 2020 and February 24, 2020. The Customer's solution was installed on panels connected to a single inverter (Inverter 4) in order to evaluate the relative impact to production with respect to nearby inverter blocks likely to experience similar meteorological and soiling conditions. For this pilot study, the Customer programmed the module washing to take place at 1:00 in the evening approximately once every 3 days on all modules connected to Inverter 4.

3 RESULTS

3.1 Data processing

DNV GL was provided access to hourly data for the following variables collected at the Pilot System beginning January 1, 2018 through June 30, 2020:

- Global horizontal irradiance (*GHI*)
- Ambient air temperature (*Tamb*)
- Real ac power measured at the revenue meter (*Pac_poi*)
- Real ac power measured at each of the 13 23kW-inverters (*Pac_invXX*)
- Expected ac power (*Pac_poi_exp*)

DNV GL conducted a high-level data quality check (including identification and correction of missing, corrupted, and out-of-range values) on all measured records and found no significant data quality issues. DNV GL notes that an independent review of the expected ac power (*Pac_poi_exp*) signal downloaded from the data platform was not completed for this study. However, due to prior experiences with the data monitoring solution provider, DNV GL considers the expected power signal to be a reasonable approximation of the generation from an optimally running system, given the *GHI* and *Tamb* conditions recorded at a given time. DNV GL notes that the *Pac_poi_exp* signal differs from the budgeted power of a system as modeled by a *pro forma* energy model in that the *Pac_poi_exp* signal reflects the actual measured weather conditions experience on site at any given point in time. This analysis will rely on this expected power signal to quantify the amount of soiling affecting the system each day.

3.2 Performance Index and Soiling Signatures

DNV GL defines a Performance Index (*PI*) to be the ratio of the actual measured power divided by the expected power over some period of time. A *PI* of unity indicates that the system had been performing exactly as expected, while a *PI* below one (1.0) is an indication of underperformance with respect to expectations. For instance, a daily *PI* = 0.9 indicates that the system was producing 10% less energy than expected given the weather conditions that day.

DNV GL notes that the *Pac_poi_exp* signal can be a source of error for *PI* for two main reasons: 1) the underlying energy model used to derive *Pac_poi_exp* does not have good fidelity to the as-built system and therefore does not actually represent optimal performance and 2) the weather data used to tune the calculations are biased or inaccurately represents on-site conditions. High-level data quality checks conducted by DNV GL found no disqualifying issues with the weather data used in this study. Since DNV GL has not independently reviewed the underlying energy model for fidelity to the as-built system, any conclusions must acknowledge some degree of uncertainty and bias that have not been ruled out.

Figure 3-1 presents a time series plot of the Pilot System's *PI* over a 2.5-year period beginning in January 2018. The blue circles represent the daily *PI*, the red line is a reference for a *PI* of 1, and the black shaded region represents the span of time when the RST solution was installed at the Pilot System. Figure 3-2 presents a time series plot of daily *PI* with additional filters applied to exclude periods of low irradiance (*GHI*<200 W/m^2) and period of unusually low performance (*PI*<0.5) in order to better isolate the impact due primarily to soiling.

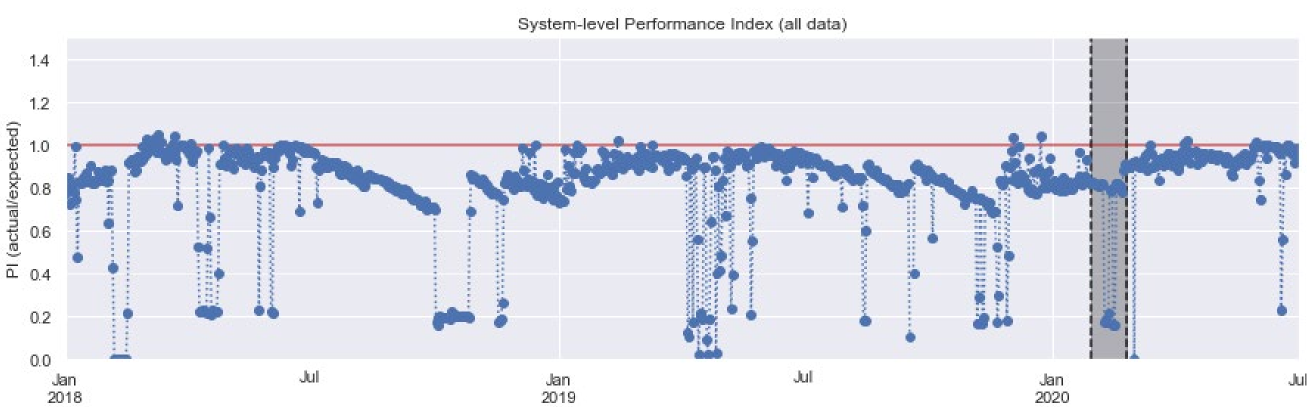

Figure 3-1: Daily Performance Index of power for Pilot System

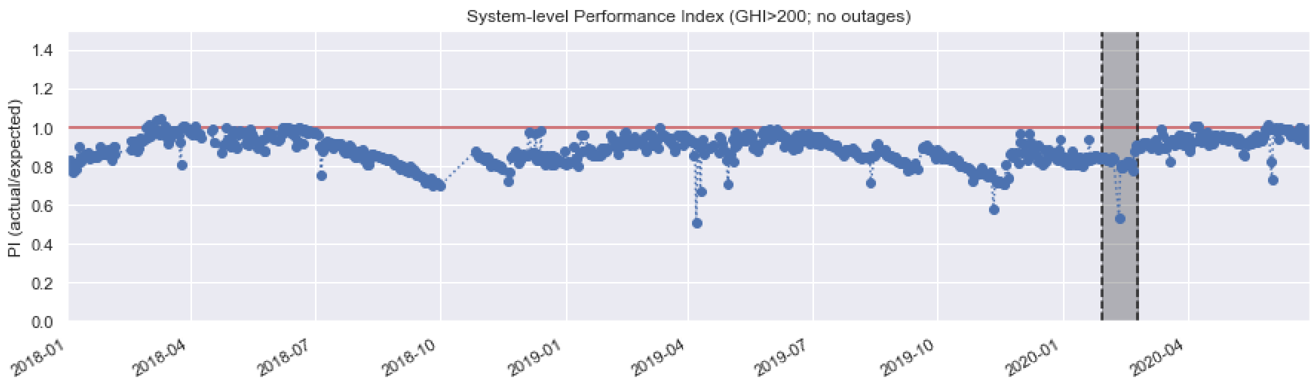

Figure 3-2: Daily Performance Index of power for Pilot System (irradiance and availability filtered)

Evidence of dust soiling is particularly apparent in Figure 3-2 during the summer months in both 2018 and 2019, where the soiling impact on production reached nearly 30% loss at the start of October 2018 and again around November 2019. The steady linear decline observable between July and October 2018 reflects the canonical signature of dust build-up first described in [1]. Performance data also reveal the Pilot System is subject to high amounts of soiling build-up in the summer months when precipitation is rare, yielding soiling rates on the order of 0.33% energy loss per day, which is severe compared to other projects located in urban settings.

Figure 3-3 presents a time series plot of *PI*s derived for each of the 13 inverters rated at 23 kWac. The expected energy for each of these 13 inverters was computed by scaling the *Pac_poi_exp* signal by each inverter's peak power taken from the 2.5 years of operating data (see Table 3-1). The inverter-level *PI* was then computed as the ratio of actual *Pac_inv* divided by *Pac_inv_exp* for a given period of time.

Table 3-1: Derived capacities of 23 kWac inverters used to scale *Pac_poi_exp*

Inverter	1	2	3	4	5	6	7	8	9	10	11	12	13
kWac	18.8	23.1	23.1	23.1	23.1	23.1	23.1	23.1	23.1	23.0	23.0	23.0	23.1
% of system	1.5%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%

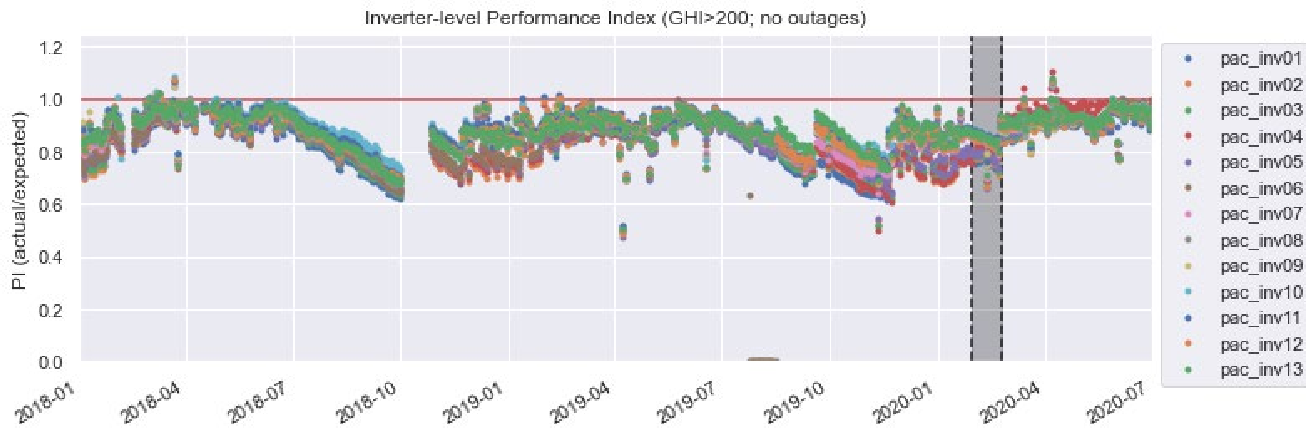

Figure 3-3: Daily Performance Index of power for the thirteen 23 kWac inverters at Pilot System (irradiance and availability filtered)

3.3 Energy recovered

Table 3-2 presents the difference in average *PI* between Inverter 4 and the other 12 inverters for 6 different time periods. Below are the definitions of the various time periods of data considered in this study:

- The "All data" period starts 1 January 1, 2018 and goes through January 28, 2020
- The "4 months prior to RST" period starts September 7, 2019 and goes through January 25, 2020
- The "Spring 2018" period starts February 25, 2018 and goes through June 30, 2018
- The "Spring 2019" period starts February 25, 2019 and goes through Jun 30, 2019
- The "4 months after RST" period starts February 25, 2020 and goes through June 30, 2020
- The "Between rain after RST" period starts April 12, 2020 and goes through May 18, 2020

Results computed with data from different time periods are present to show the range of variations that exists between how inverters at the Trial System perform at different times. For example, the average *PI* for Inverter 1 was approximately 6.2% less than the average *PI* for Inverter 4 over approximately four (4) months following the installation and use of the RST solution.

Table 3-2: Difference in Performance Index relative to Inverter 4 over 6 different time periods

	All data	4 months prior to RST	Spring 2018	Spring 2019	4 months after RST	Between rain after RST
Inverter 1	-2.2%	-1.6%	-1.9%	-1.4%	-6.2%	-7.1%
Inverter 2	-0.5%	-0.2%	-0.1%	-0.5%	-5.3%	-5.9%
Inverter 3	0.3%	0.8%	<0.1%	0.5%	-4.8%	-5.6%
Inverter 5	<0.1%	3.6%	-0.9%	-0.7%	-4.5%	-5.5%
Inverter 6	0.2%	--	<0.1%	<0.1%	--	--
Inverter 7	2.4%	6.4%	1.8%	0.7%	-4.0%	-5.3%
Inverter 8	2.0%	8.4%	1.0%	0.6%	-3.7%	-5.0%
Inverter 9	4.1%	9.2%	2.4%	0.9%	-4.2%	-5.4%
Inverter 10	4.8%	11.0%	3.1%	1.3%	-3.9%	-5.2%
Inverter 11	4.0%	9.9%	2.4%	1.6%	-3.7%	-5.1%
Inverter 12	2.8%	8.5%	1.1%	1.1%	-3.9%	-5.2%
Inverter 13	2.9%	10.8%	1.5%	0.3%	-3.0%	-4.3%

Figure 3-4 shows a zoomed-in view of the inverter-level *PI* time series plot to highlight the soiling conditions impacting the inverters during an approximately 4-month period before and after the installation of the Customer’s equipment. During the “4 months prior to RST” period, the performance impact from soiling was not uniform across the inverters, as evidenced by the rather large range (~20%) in inverter-level *PI*s observed prior to the trial commencement. While the distinct signatures of soiling accumulation can be observed in the in October and November timeframe, the large spread between the highest and lowest inverter-level *PI* indicates soiling was affecting the performance of some inverters more than others. Moreover, the *PI* signals become much more convoluted and even seemingly grouped into two clusters by January 2020. It is entirely possible that certain areas of the Pilot System experienced heavier soiling than others. DNV GL recommends utilizing a different period in the data record for establishing a reference baseline to quantify the relative energy impact of the RST solution on the Pilot System.

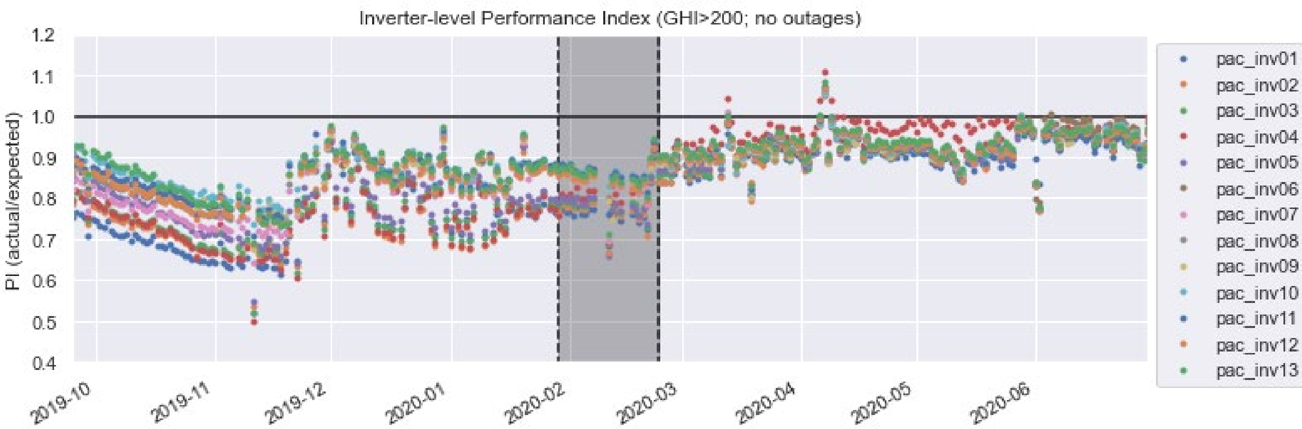

Figure 3-4: Inverter-level PI zoomed into the trial period

Figure 3-3 shows several alternative periods in the operating history of the Pilot System where soiling impacts are much more uniformly experienced across all inverters and which could serve as a more unbiased baseline of comparison. Two such periods are, in fact, the March through June months in both 2018 and 2019 (see Figure 3-5 and Figure 3-6). Not only was the spread in inverter-level *PI*s smaller over these two periods, but the equivalent seasonality with respect to weather conditions and intensity of irradiation with respect to the post-RST data makes the comparison more compelling.

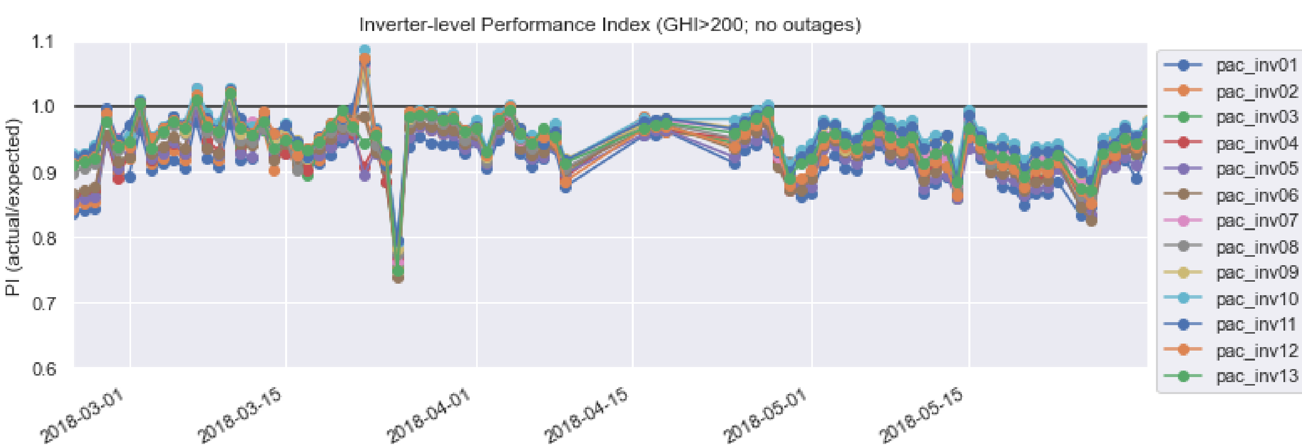

Figure 3-5: Inverter-level PI for spring 2018

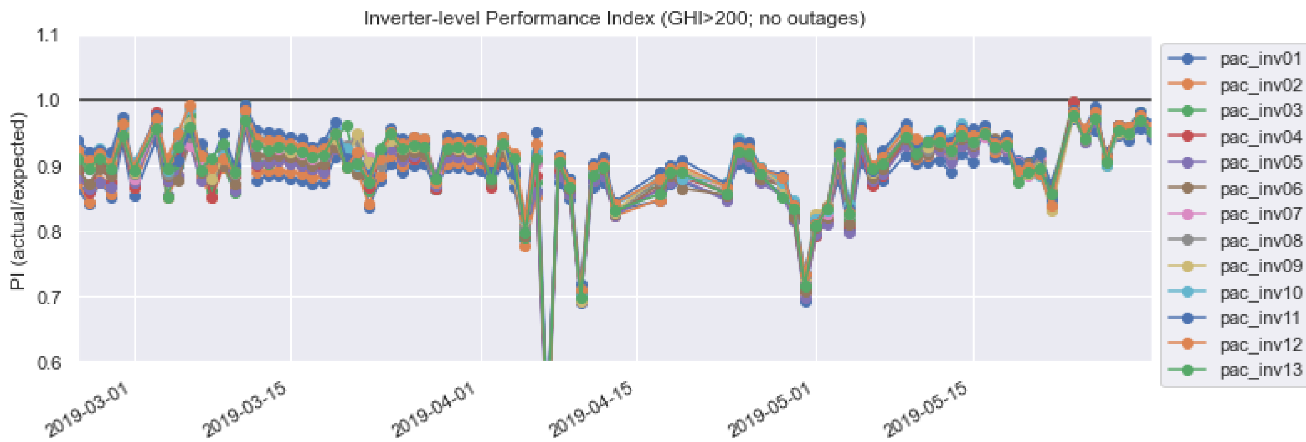

Figure 3-6: Inverter-level PI for spring 2019

Figure 3-7 shows the inverter-level *PI* for the "4 months after RST" period when the Customer's solution had been deployed and actively washing the panels connected to Inverter 4. The vertical blue lines mark days with rainfall and the yellow highlights the "Between rain after RST" period occurring between rain events when the soiling build-up on all inverters other than Inverter 4 can be observed with great clarity. It is especially unmistakable during the "Between rain after RST" period that Inverter 4 is producing more power (higher *PI*) than the other Inverter blocks, which can be attributable to module washing with high confidence.

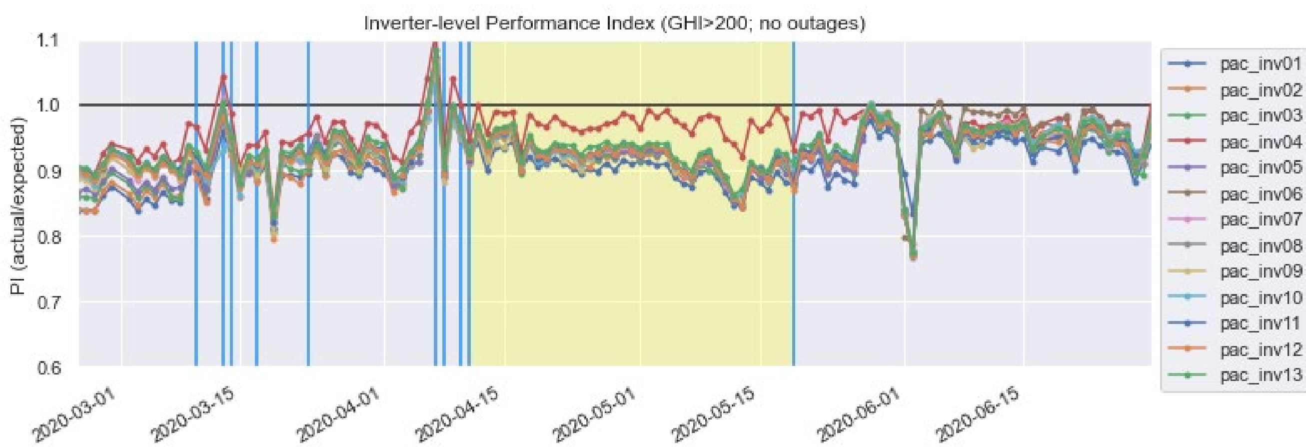

Figure 3-7: Inverter-level *PI* for the period after RST solution installed (blue lines indicate rain events; yellow highlights period when soiling build-up disparity is most apparent)

Of the defined data periods recorded prior to the installation of the RST solution, DNV GL considers the "Spring 2018" and "Spring 2019" to be the most representative of a baseline relationship between the inverters. The "All data" and "4 months prior to RST" periods both contain instances when soiling conditions differed by more than 20% across inverters, including the severe soiling present during the mid- to late-summer months. On the other hand, of the 2 selected time periods recorded after the installation of the RST solution, DNV GL considers the "Between rain after RST" to be more representative of the energy recovery potential provided by the RST solution than the entire "4 months after RST", since the former isolated a period without rain or manual washing that allowed sufficient soiling to build upon unwashed inverter blocks to more distinctly illustrates the ability of the RST solution to reduce soiling.

Table 3-3 shows an estimate of the energy impact of the Customer's module washing solution as a percentage of expected energy. For example, the average energy recovery across all inverters comparing the "Between rain after RST" period and "Spring 2019" was 5.8%.

Table 3-3: Percent recovered energy over "Between rain after RST" period and normalized by *PI*s from various baseline periods

	All data	4 months prior to RST	Spring 2018	Spring 2019
Inverter 1	5.0%	5.6%	5.2%	5.7%
Inverter 2	5.4%	5.7%	5.8%	5.4%
Inverter 3	5.9%	6.4%	5.6%	6.1%
Inverter 5	5.5%	9.0%	4.6%	4.8%
Inverter 6*	-	-	-	-
Inverter 7	7.6%	11.7%	7.1%	5.9%
Inverter 8	7.0%	13.4%	5.9%	5.6%
Inverter 9	9.5%	14.6%	7.8%	6.3%
Inverter 10	10.0%	16.2%	8.2%	6.5%
Inverter 11	9.1%	15.0%	7.5%	6.8%
Inverter 12	8.0%	13.7%	6.3%	6.3%
Inverter 13	7.2%	15.2%	5.9%	4.6%
Average	**7.3%**	**11.5%**	**6.4%**	**5.8%**

*Inverter 6 experienced communication outage throughout much of 2020

4 CONCLUSIONS AND RECOMMENDATIONS

Due to the varied influence of local meteorological conditions (e.g., relative humidity, precipitation patterns, cloudiness), system configuration (e.g., fixed-tilt or tracker, dc-to-ac ratio), as well as local land-use type (e.g., heavy agricultural, urban industrial), production impacts from dust soiling are difficult to predict with precision. Therefore, while DNV GL cannot provide a generalized prediction for the maximum or even the expected energy savings of installing the RST solution on any given system, DNV GL can conclude that the Customer has demonstrated their solution was capable of reducing soiling build-up at the Pilot System. Using the wash settings described in Sections 1 and 2 of this report, the RST solution was able to significantly mitigate the buildup of soiling on modules connected to Inverter 4, allowing those modules to operate closer to their nameplate capacities than those left untreated. Over a 4-week period from April 12, 2020 to May 18, 2020, when no rain or other module-washing events took place, the inverter outfitted with the RST solution saw an improvement in production on the order of 6% better than baseline conditions over just that period. Figure 3-7 shows that the *PI* for Inverter 4 was maintained at or above 95% throughout this period while every other inverter demonstrated a sustained and correlated decline in output. DNV GL notes that the soiling rate during this period was estimated to be approximately -0.15%/day compared to the extreme soiling rate of nearly -0.33%/day observed in the late summers of 2018 and 2019. Therefore, if this trial study were extended into the late summer months of Aug and Sept, when this project location has historically experienced the heaviest soiling losses, DNV GL expects the RST solution to yield even greater energy savings.

5 REFERENCES

[1] A. Kimber, L. Mitchell, S. Nogradi and H. Wenger, "The Effect of Soiling on Large Grid-Connected Photovoltaic Systems in California and the Southwest Region of the United States," *2006 IEEE 4th World Conference on Photovoltaic Energy Conference*, Waikoloa, HI, 2006, pp. 2391-2395, doi: 10.1109/WCPEC.2006.279690.

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