Solectria Renewables

Inverter Field Testing
Engineering Report

October 10, 2014

20 pages

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Summary

Solectria Renewables, LLC has contracted PV Evolution Labs (DNV GL PVEL LLC) to deploy and monitor two (2) PVI 28TL, 28 kW grid-tied transformerless string inverters with dual maximum-power-point trackers (MPPTs) at the PVUSA test and research facility in Davis, CA. The purpose deployment and monitoring of the PVI 28TL inverters is to evaluate their performances under real-world operating conditions. Deployment and monitoring of the inverters occurred over a Monitoring Period from March to June 2014. In this report, the conversion efficiencies and operating temperatures are evaluated over a Test Period from April 9th to May 9th, 2014, and the installation characteristics of the inverters are noted.

Conclusions

Over the four (4) month Monitoring Period, the two (2) Solectria PVI 28TL inverters operated reliably with no service interruptions.

During the month-long Test Period, the inverters achieved an average daily run-time of six-hundred and ninety-seven (697) hours and converted an average of five-thousand five-hundred and fifteen (5515) kilowatt-hours (kWh) of energy. The peak efficiencies of Inverter 1 and Inverter 2 under normal operating conditions at the PVUSA test and research facility were determined as 97.8 % at an output power of 9 kW.

The optional Shade Plate was installed on Inverter 1 during approximately half of the test period, and decreases in Inverter 1 case temperatures of 15.65 %, 6.26 %, and 4.20 % at the top, front, and back sides, respectively, of the inverter were measured.

The ease of installation of the Solectria PVI 28TL inverter was noted by the field installers. However, the Shade Plate has issues that should be remedied to improve the ease and functionality of its installation.

Systems Details

The major photovoltaic (PV) array characteristics connected to the two (2) Solectria PVI 28TL inverters are listed in Table 1 below. The PV arrays are in a fixed configuration and are composed of a variety of BP Solar modules of similar operating voltages. The irradiance, power, and weather measurement devices are listed in Table 2 below along with their associated measurement uncertainties.

	Inverter 1	Inverter 2
Inverter	Solectria Renewables PVI 28TL	Solectria Renewables PVI 28TL
Grid Connection	480 VAC, 3Φ	
Module Types	BP Solar BP2150S, BP4165T, BP175B, SX3175N	
Total Number of Strings	14	
Number of Strings on Inverter MPPT 1	7	
Number of Strings on Inverter MPPT 2	7	
Modules per String	20	
Nameplate DC System Power	42 kW (approximate)	
DC System Voltage	650 V (approximate)	
System Location	PVUSA (Davis, CA)	
System Orientation	0° zenith, 350° azimuth	
Testing Dates	April 9th to May 9th, 2014	

Table 1 Major characteristics of the inverter systems and their PV arrays

Parameter	Equipment	Uncertainty
AC power	Shark 100	± 1 %
DC power, current and voltage	Current shunts with Advantech ADAM 4117	± 2 %
Plane-of-array (POA) irradiance	Photovoltaic reference cell	± 2 %
Module temperature	Type-T thermocouple	± 1° C
Wind speed	Vaisala WXT520	Greater of ± 0.3 m/s or ± 3 %
Wind direction	Vaisala WXT520	± 3°
Ambient temperature	Vaisala WXT520	± 0.3° C
Precipitation (rain, hail)	Vaisala WXT520	± 5 %
Relative humidity	Vaisala WXT520	± 3 %
Barometric pressure	Vaisala WXT520	± 0.5 hPa

Table 2 Inverter performance and weather monitoring equipment details and associated measurement uncertainties

Systems Details

Figure 2 Image of the installations of the two (2) Solectria PVI 28TL – the inverter on the right-hand side of the image has a shade cover installed

Figure 1 above is an image of the two (2) Solectria PVI 28TL installed at PVUSA. Inverter 1 is located on the right-hand side of the image with its shade cover installed. Inverter 2 is located on the left-hand side of the image without a shade cover. The locations of the installed thermocouples installed on the inverters to monitor case temperatures during the Test Period are shown in Figure 2 below.

Systems Details

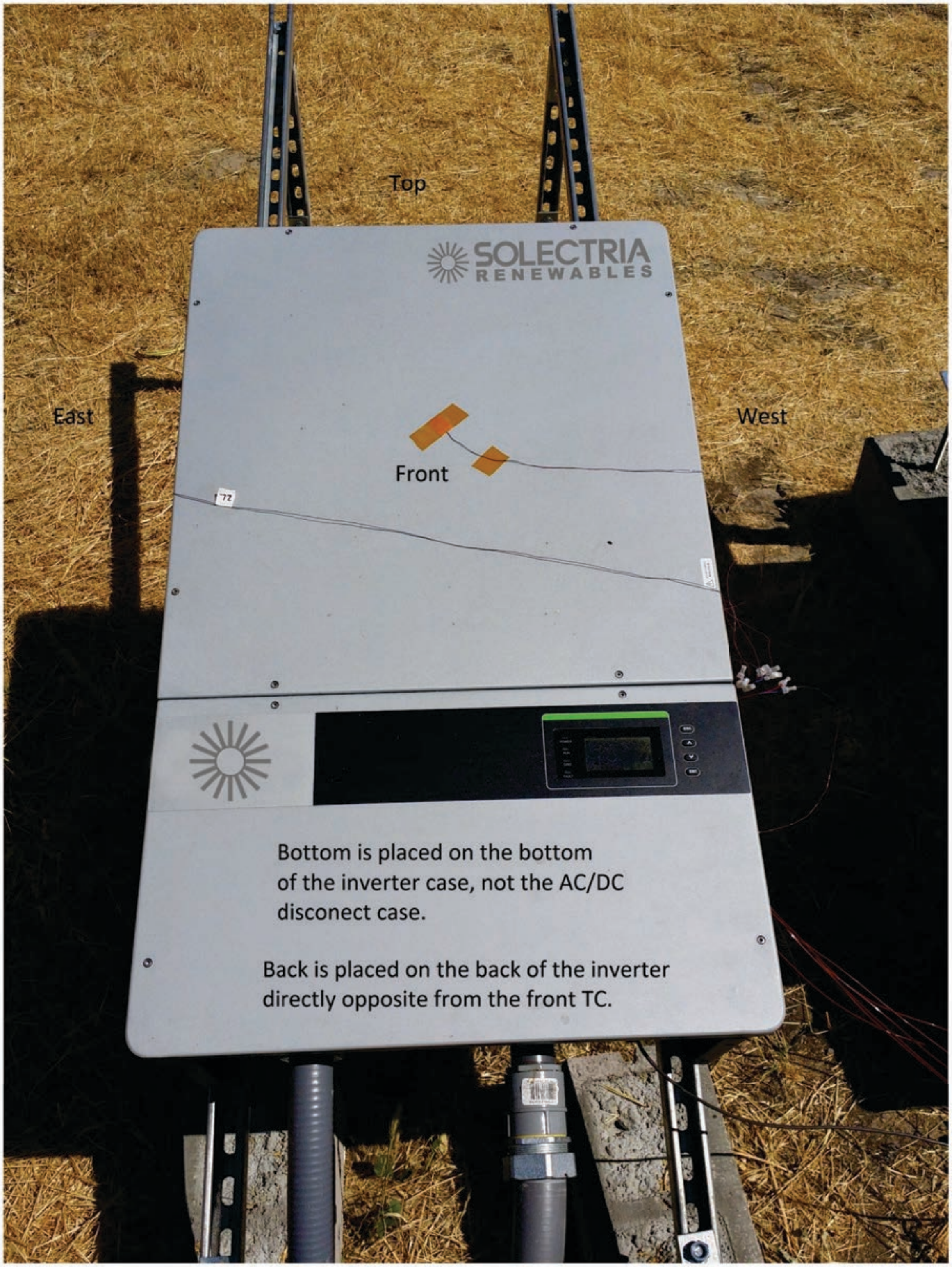

Figure 2 Image indicating thermocouple placements

Monitoring of Inverters

During the Monitoring Period, many operational parameters of each inverter were obtained from the inverters and recorded. The information extracted from each inverter is listed in Table 3 below. The average daily run-times of the inverters during the Test Period are listed in Table 4 below. The daily run-time values are a function of local insolation, the positions of the associated PV arrays with respect to objects in the test field that shade the arrays during early morning and late afternoon periods, and any inverter faults that occurred. No inverter faults occurred during the Test Period, which aided in achieving the excellent daily run-times.

DC Parameters	AC Parameters	Other Parameters
DC Voltage MPPT 1 (V)	Phase AB Voltage (V)	Energy - Per Day (kWh)
DC Current MPPT 1 (A)	Phase AB Current (V)	Energy - Running Total (kWh)
DC Voltage MPPT 2 (V)	Phase AC Voltage (V)	Run Time - By Day (minutes)
DC Current MPPT 2 (A)	Phase AC Current (V)	Efficiency (%)
DC Power (kW)	Phase BC Voltage (V)	Inverter Temperature (°C)
	Phase BC Current (V)	Ambient Temperature (°C)
	Real AC Power (kW)	Isolation Resistance (kΩ)
	Apparent AC Power (kVA)	
	Power Factor	
	Frequency (Hz)	

Table 3 Operating parameters directly monitored by inverters are recorded over the monitoring period

Inverter 1 Run-time (minutes)	Inverter 2 Run-time (minutes)
685	708

Table 4 Average daily run-time of the inverters over the Test Period

Performance Evaluations

Inverter Production

The energy converted by the inverters over the Test Period are listed in Table 5 below. The energy converted by the inverters is a function of local insolation on each PV array over the Test Period and the DC capacity of each PV array.

Inverter 1 Energy Conversion (kWh)	Inverter 2 Energy Conversion (kWh)
5554	5476

Table 5 Energy converted by the inverters over the Test Period

The AC power output of each inverter versus irradiance incident on the plane-of-array (POA) is shown in the plot of Figure 3. Inverter clipping is evident in the plot at 28 kW. Figures 4 – 7 below are weekly plots of AC output power and irradiance for both inverters over the Test Period

Performance Evaluations

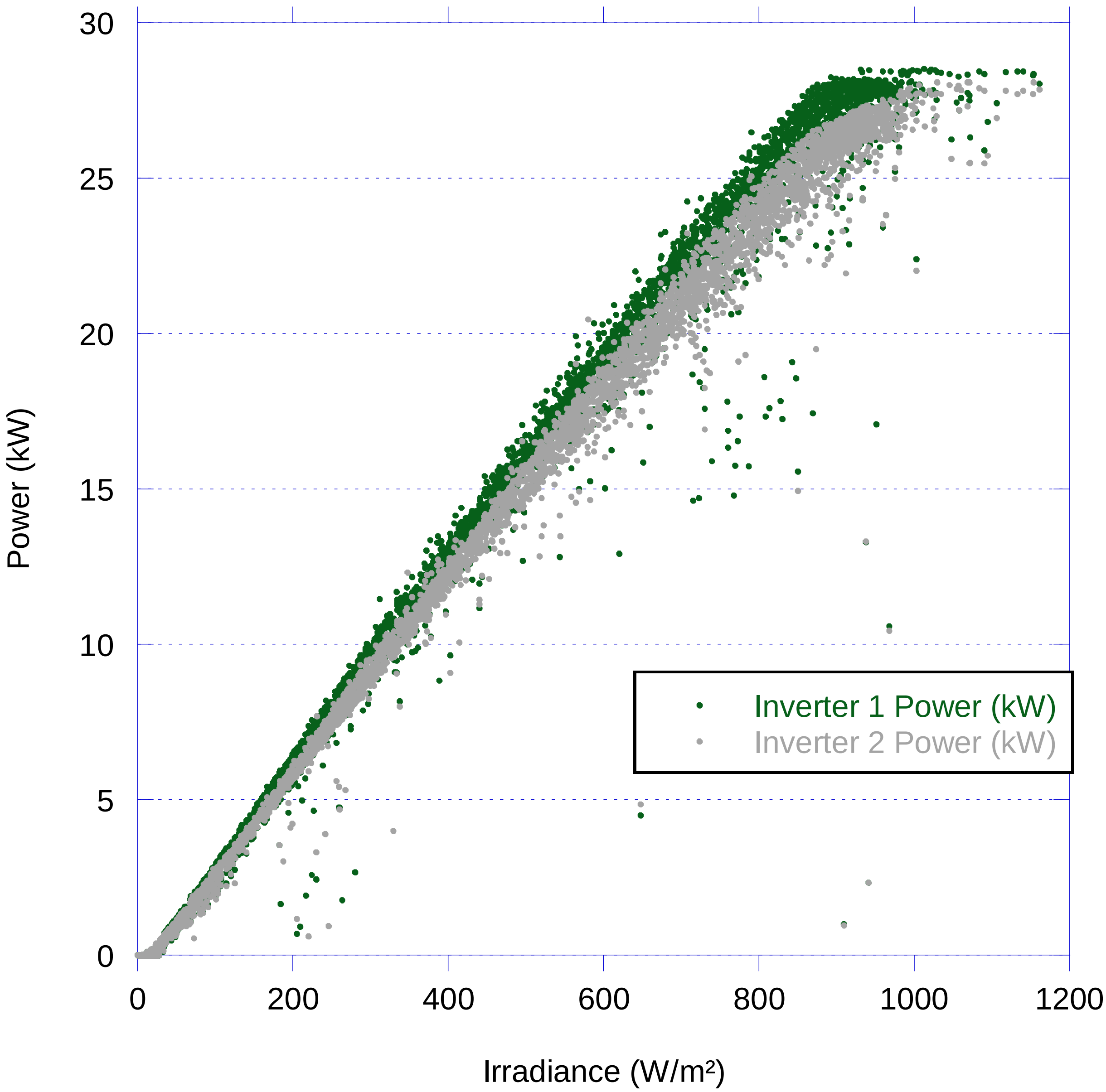

Figure 3 Plot of AC output power versus irradiance for both inverters over the Test Period

Performance Evaluations

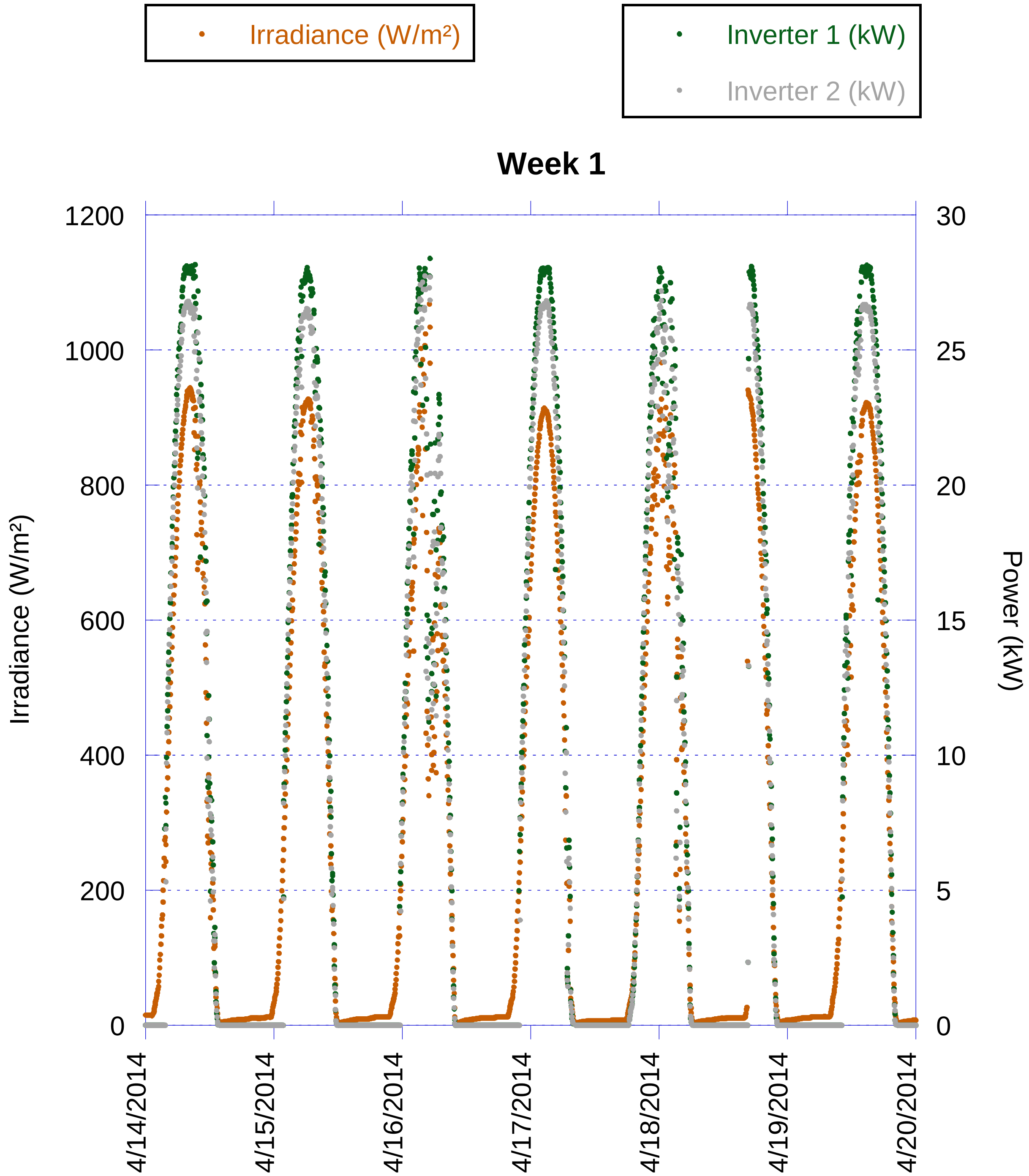

Figure 4 Plot of AC output power and irradiance for both inverters over Week 1 of the Test Period

Performance Evaluations

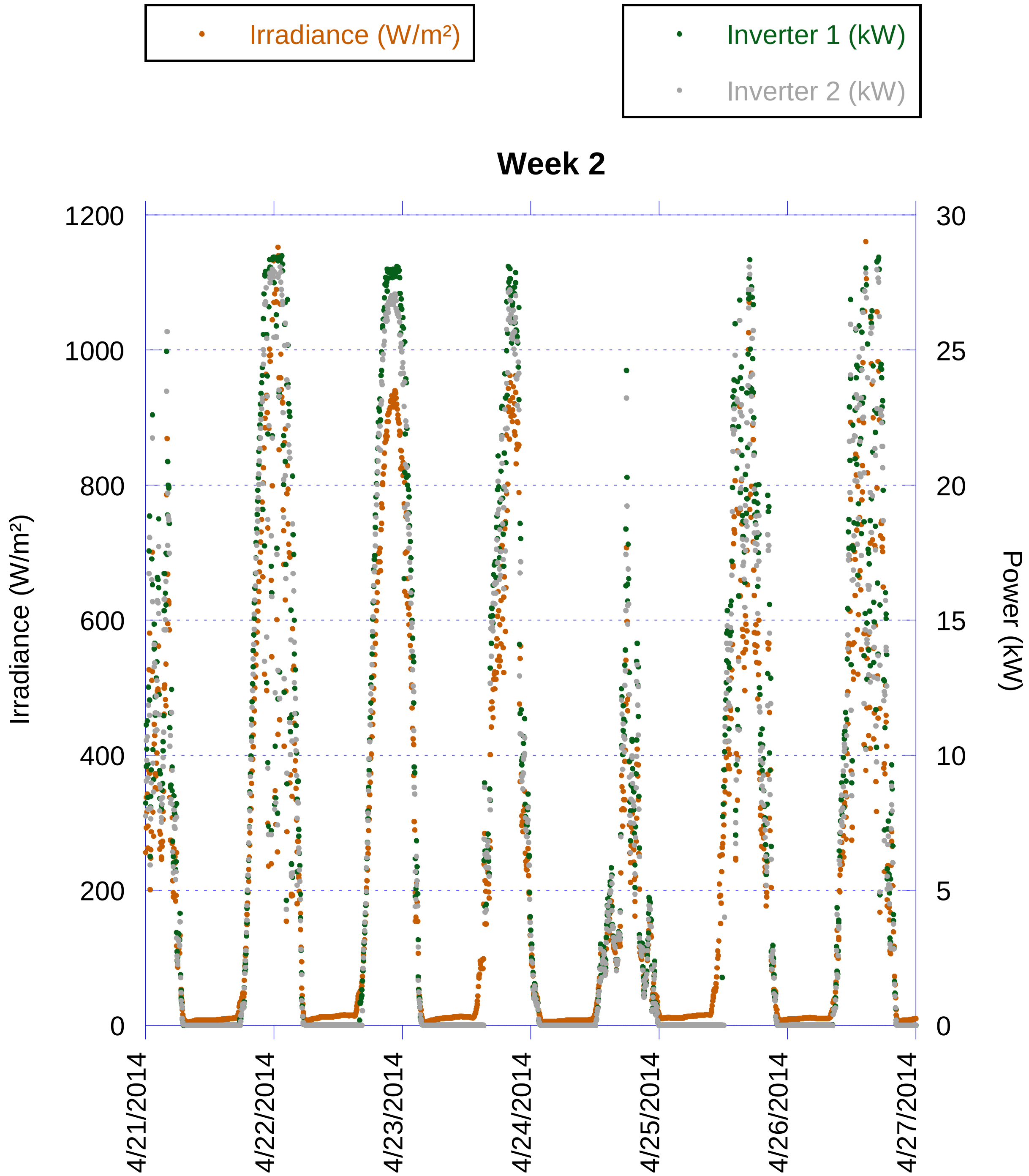

Figure 5 Plot of AC output power and irradiance for both inverters over Week 2 of the Test Period

Performance Evaluations

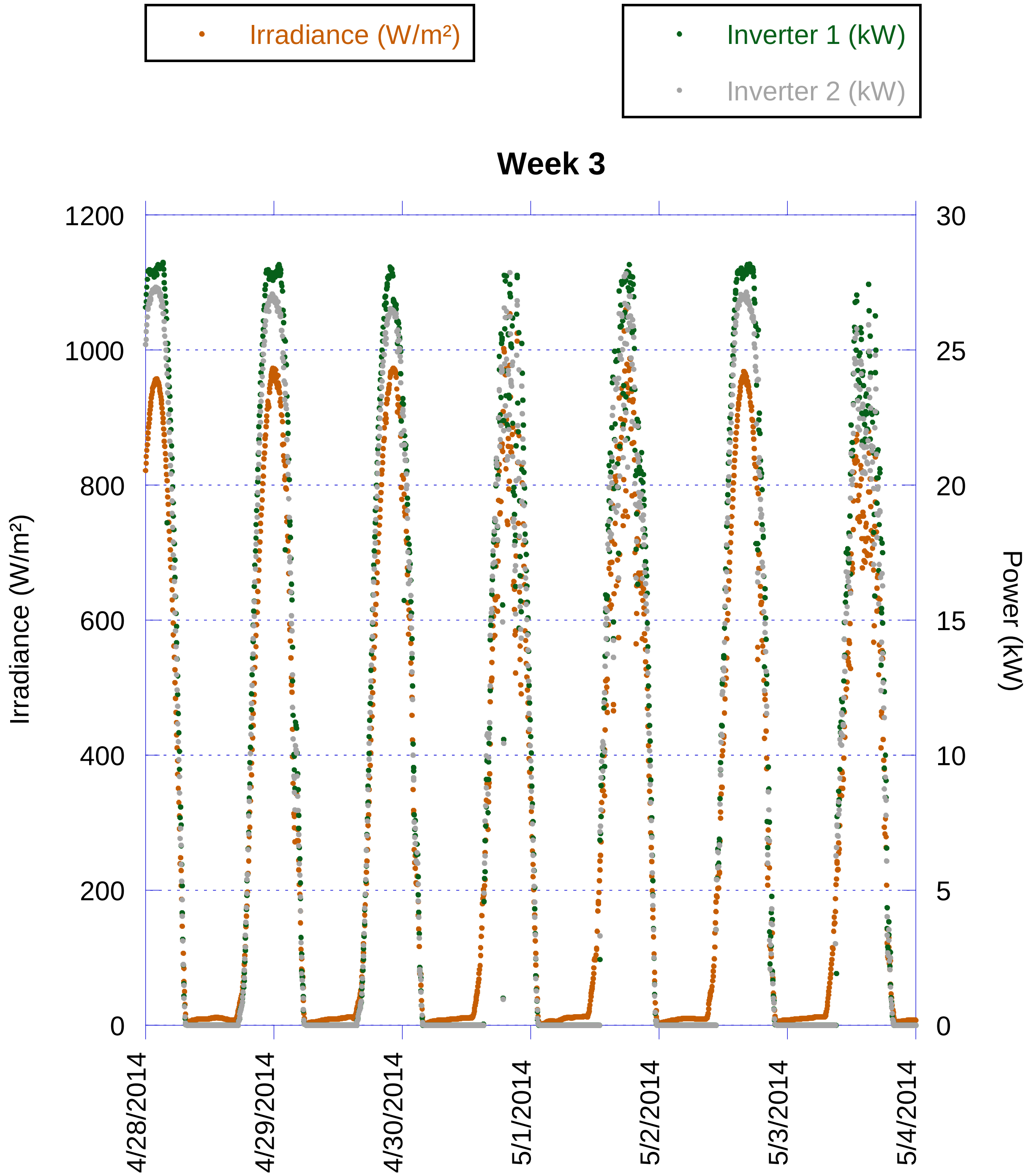

Figure 6 Plot of AC output power and irradiance for both inverters over Week 3 of the Test Period

Performance Evaluations

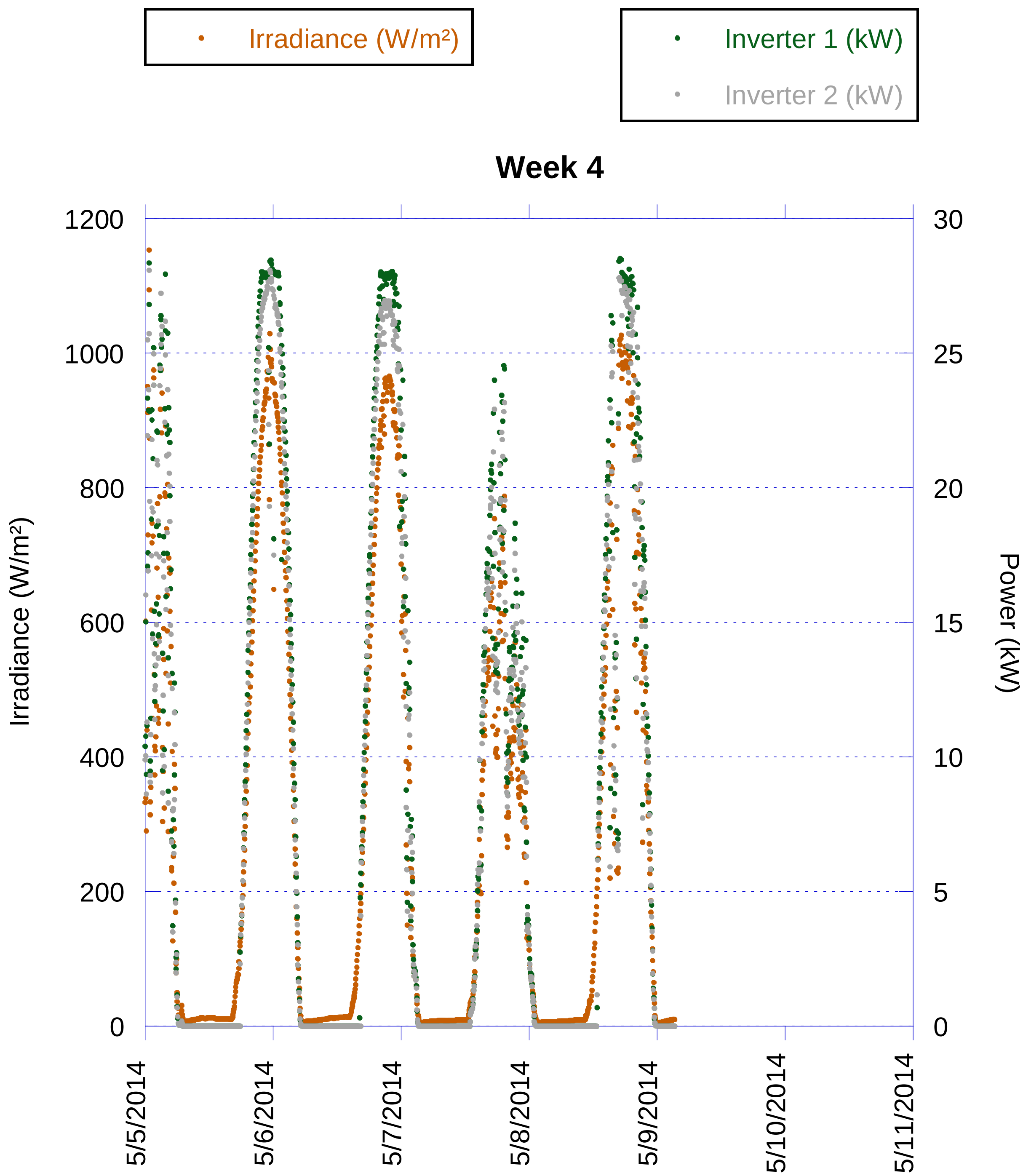

Figure 7 Plot of AC output power and irradiance for both inverters over Week 4 of the Test Period

Performance Evaluations

Inverter Efficiency

In order to evaluate the conversion efficiencies of the inverters over the Test Period, both DC input powers of the two (2) MPPT inputs of each inverter as well as the AC output powers of each inverter were measured and recorded at five-minute intervals. Measured data for which either the total DC input power (the sum of the MPPT input powers) is less than 0.5 kW or calculated efficiency is greater than 100 % are neglected from this analysis. Figure 8 below is a plot of measured conversion efficiency versus output power of Inverter 1 over the Test Period.

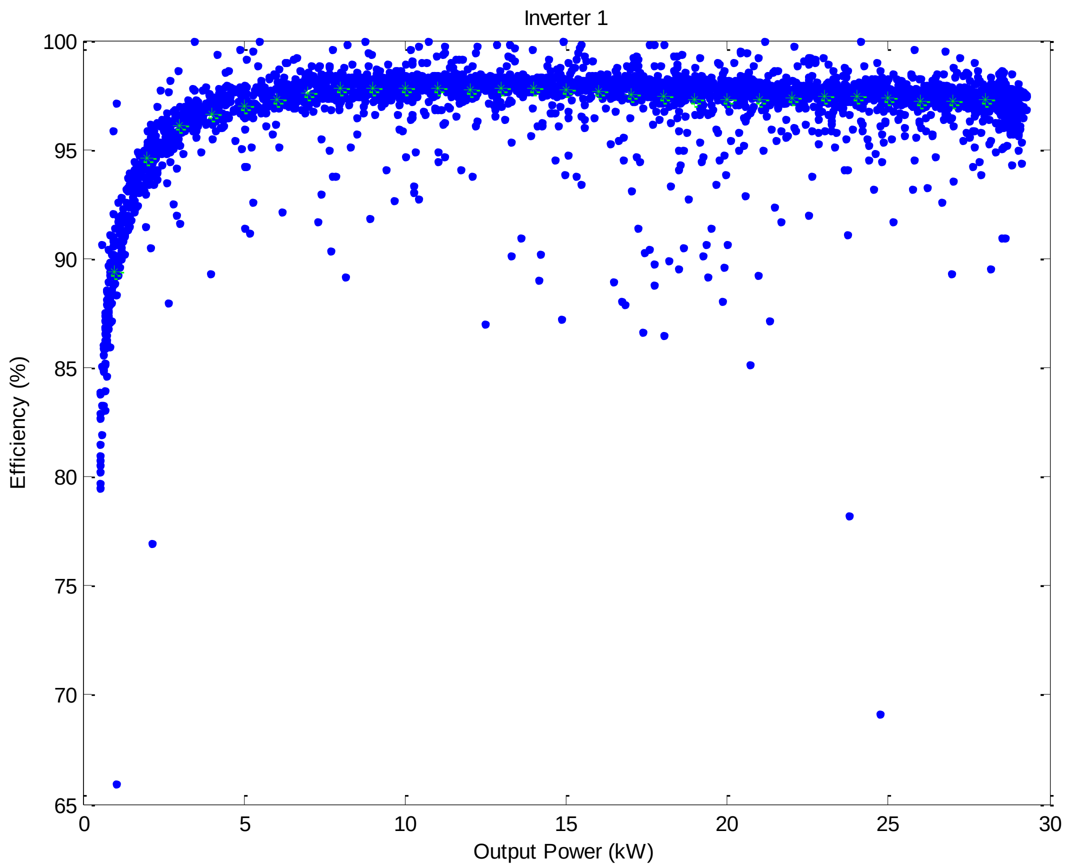

Figure 8 Inverter 1 conversion efficiency versus output power (blue dots) and the resulting tenth-order polynomial fit (green asterisks) evaluated over the output power range at 1 kW intervals

Performance Evaluations

Figure 9 below is a plot of measured conversion efficiency versus output power of Inverter 2 over the Test Period.

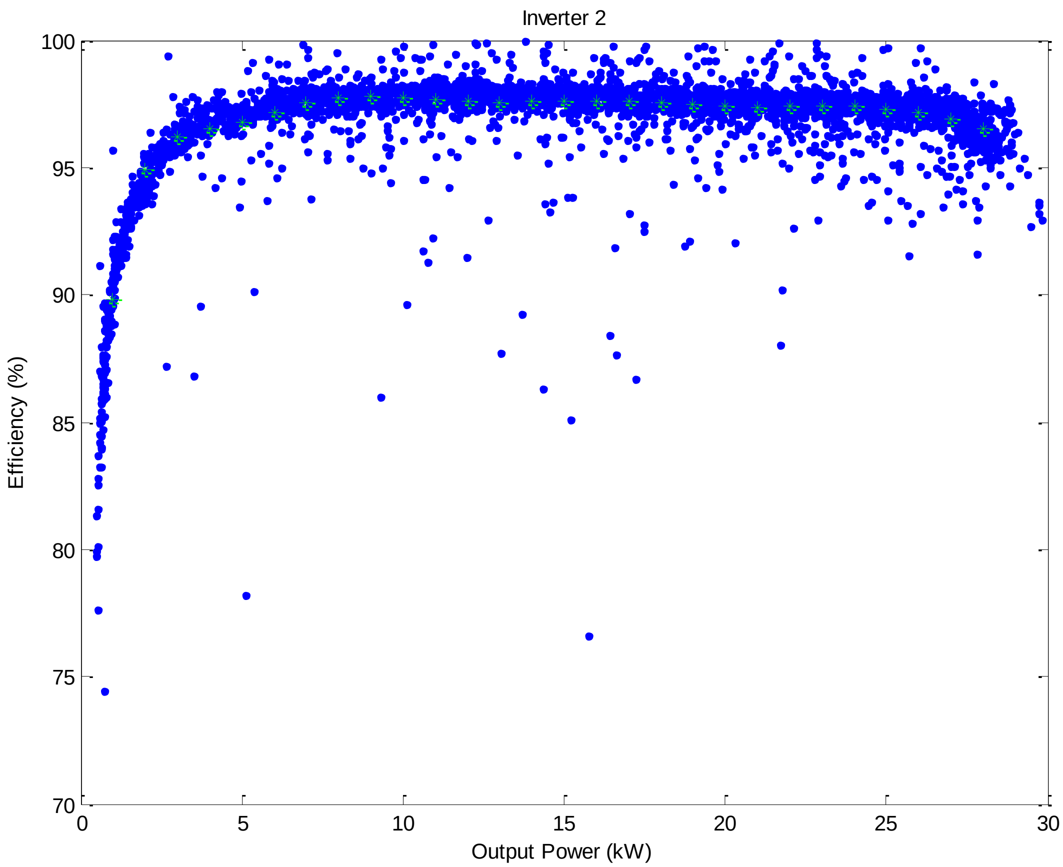

Figure 9 Inverter 2 conversion efficiency versus output power (blue dots) and the resulting tenth-order polynomial fit (green asterisks) evaluated over the output power range at 1 kW intervals

Performance Evaluations

Table 5 below contains the conversion efficiencies of both Inverter 1 and Inverter 2 calculated using the tenth-order polynomial fits of the measured data of each inverter that are evaluated throughout the Solectria PVI 28TL output range at intervals of 1 kW.

Output Power (kW)	Inverter #1 Efficiency (%)	Inverter #2 Efficiency (%)
1	89.4	89.8
2	94.6	94.9
3	96.1	96.2
4	96.6	96.5
5	97.0	96.8
6	97.3	97.2
7	97.6	97.5
8	97.8	97.7
9	97.8	97.8
10	97.8	97.7
11	97.8	97.6
12	97.8	97.6
13	97.8	97.6
14	97.8	97.6
15	97.7	97.6
16	97.7	97.6
17	97.5	97.6
18	97.4	97.5
19	97.3	97.5
20	97.3	97.4
21	97.3	97.4
22	97.4	97.4
23	97.4	97.4
24	97.4	97.4
25	97.3	97.3
26	97.2	97.1
27	97.2	96.9
28	97.3	96.5

Table 5 Calculated efficiencies of Inverter 1 and Inverter 2 using tenth-order polynomial fits of measured performance data

Performance Evaluations

Table 6 below contains the coefficients of the tenth-order polynomial fits applied to the performance data of Inverter 1 and Inverter 2.

Polynomial Coefficient	Inverter #1	Inverter #2
c0	7.458E+01	7.422E+01
c1	2.308E+01	2.452E+01
c2	-1.056E+01	-1.146E+01
c3	2.712E+00	2.940E+00
c4	-4.246E-01	-4.534E-01
c5	4.245E-02	4.429E-02
c6	-2.761E-03	-2.805E-03
c7	1.162E-04	1.148E-04
c8	-3.050E-06	-2.929E-06
c9	4.531E-08	4.238E-08
c10	-2.908E-10	-2.654E-10

Table 6 Coefficients of the tenth-order polynomial fits of the performance data of Inverter 1 and Inverter 2

Performance Evaluations

Inverter Operating Temperatures

In addition to evaluating the conversion efficiencies of the inverters over a wide range of loadings, the external case temperatures of Inverter 1 and Inverter 2 were monitored over same the Test Period under the associated operating conditions. Figure 10 below are the temperatures measured at various locations on the inverter's case as well as ambient temperature throughout the Test Period. Please see Figure 2 above for an image indicating the locations of the thermocouples on the inverters under test. The thermocouples labeled "Bottom" are located at the bottoms of the inverters' case, not the bottoms of the disconnect switches. The thermocouples labeled "Front" are centrally located on the inverters' front case (not considering the added dimension of the disconnect switch). The thermocouples labeled "Back" are located at the back of the inverters opposite the "Front" thermocouples. Only temperature data during output powers of the inverters of at least 10 kW are considered in the temperature analyses.

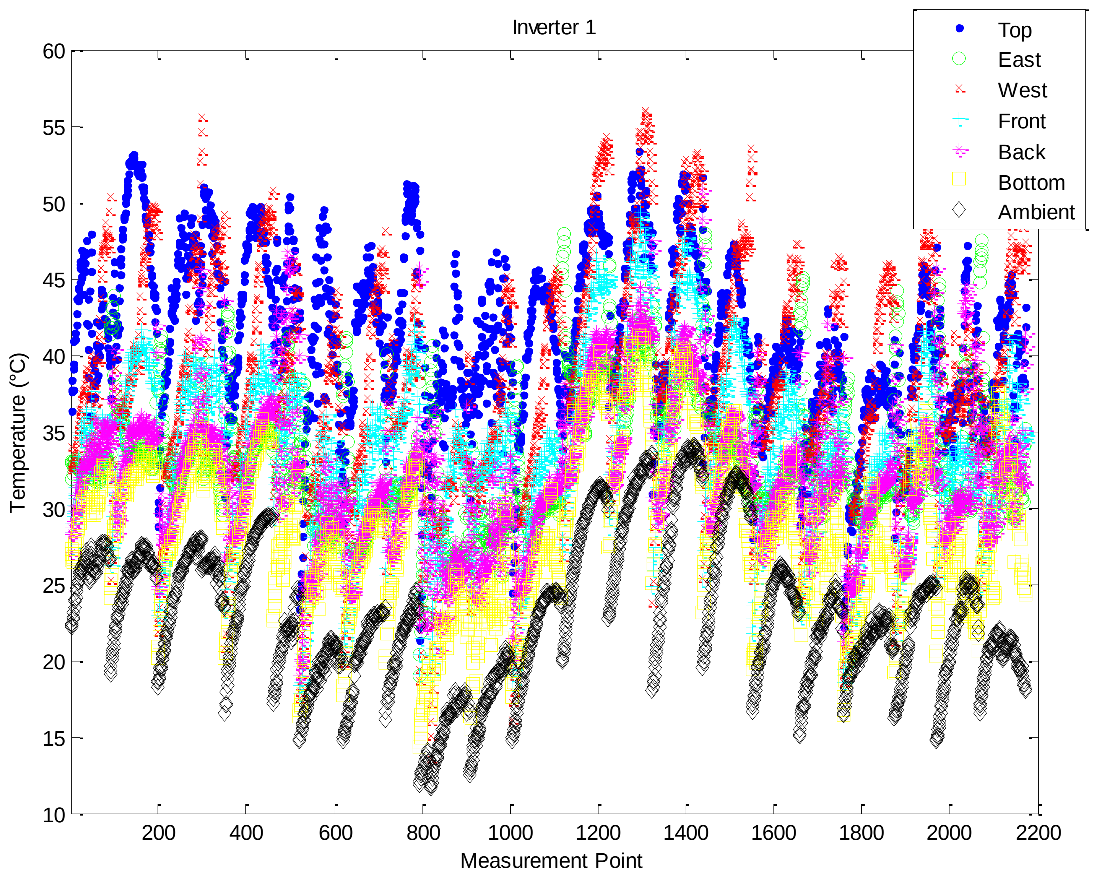

Figure 10 Inverter 1 temperatures at various locations on its case and ambient temperature throughout the Test Period

Performance Evaluations

Figure 11 below are the temperatures measured at various locations on the inverter's case as well as ambient temperature throughout the Test Period.

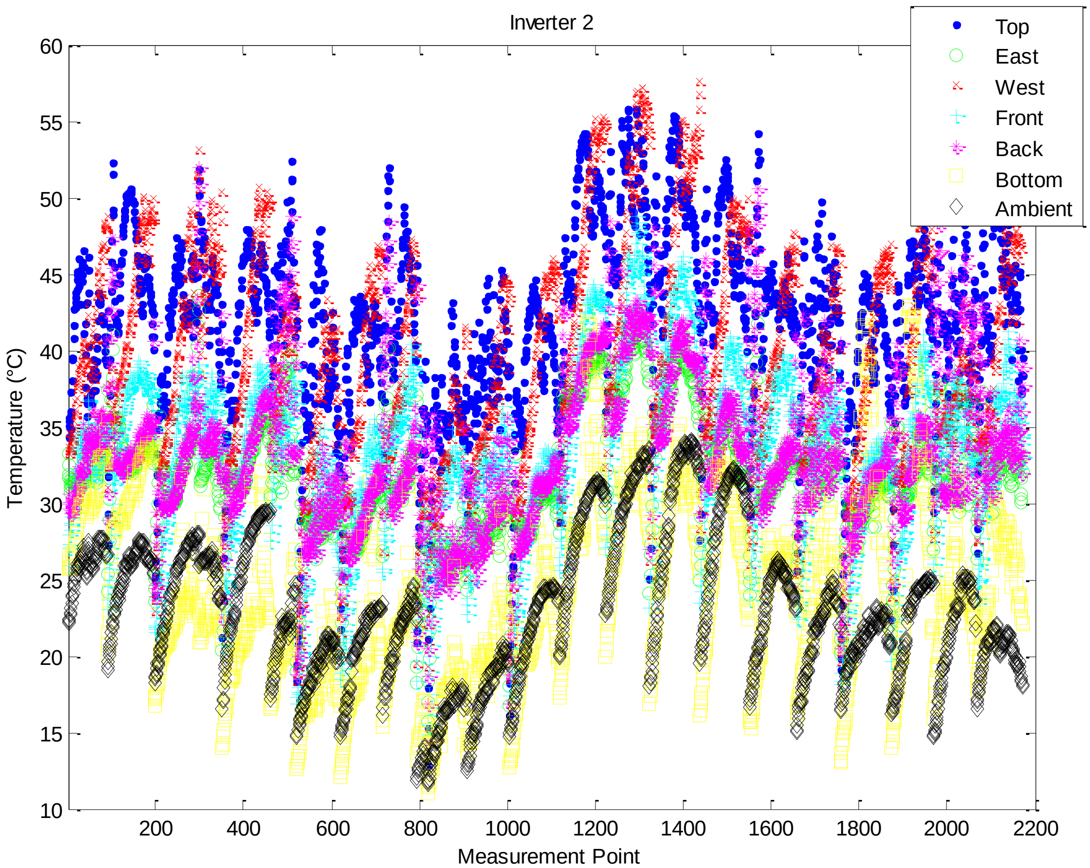

Figure 11 Inverter 2 temperatures at various locations on its case and ambient temperature throughout the Test Period

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Performance Evaluations

In order to evaluate the performance of a shade plate that may be installed on the Solectria PVI 28TL inverter, the case temperatures of Inverter 1 were recorded without the shade plate in place for the first half of the Test Period and then with the shade plate in place for the second half of the Test Period. The case temperature values of both inverters were normalized by the corresponding measured ambient temperatures, and the two (2) periods (without and with Inverter 1 shade plate) were isolated, averaged, and analyzed. Table 7 below compares the normalized case temperatures of Inverter 1 during the period with Shade Plate installation to the period without Shade Plate installation.

	Inverter 1					
Measurement Location	Top	East	West	Front	Back	Bottom
Without Shade Plate [$T_{Case}/T_{Ambient}$]	1.98	1.53	1.71	1.54	1.47	1.26
Shade Plate on Inverter 1 [$T_{Case}/T_{Ambient}$]	1.67	1.47	1.66	1.45	1.41	1.23
Percent Difference [Shade Plate - without Shade Plate] (%)	-15.65	-3.36	-3.01	-6.26	-4.20	-2.34

Table 7 Normalized (to measured ambient temperatures) case temperatures at the various locations on Inverter 1 and the percent differences between the period during which the Shade Plate was installed and the period during which the Shade Plate was not installed

Table 8 below compares the normalized case temperatures of Inverter 2 during the period with Inverter 1 Shade Plate installation to the period without Inverter 1 Shade Plate installation. Since there was never a Shade Plate installed on Inverter 2, these data are simply provided for reference to estimate the affects of variables unassociated to inverter shading on any changes in case temperature during the test period.

	Inverter 2					
Measurement Location	Top	East	West	Front	Back	Bottom
Without Shade Plate [$T_{Case}/T_{Ambient}$]	1.89	1.44	1.77	1.48	1.49	1.01
Shade Plate on Inverter 1 [$T_{Case}/T_{Ambient}$]	1.84	1.41	1.70	1.46	1.49	1.09
Percent Difference [Shade Plate - without Shade Plate] (%)	-2.88	-1.97	-3.51	-1.78	-0.54	8.37

Table 8 Normalized (to measured ambient temperatures) case temperatures at the various locations on Inverter 2 and the percent differences between the period during which the Shade Plate was installed on Inverter 1 and the period during which the Shade Plate was not installed on Inverter 1

Installation Notes

The following are substantive installations that were recorded by the field installers during the installations of Inverter 1 and Inverter 2 at PVUSA:

1. Installation of inverters
    a. The installation process was straightforward.
    b. Attaching the mounting bracket to the structure that supports the inverter was straightforward.
    c. Hanging the inverter on the mounting bracket requires two people but is straightforward.
    d. Attaching the wiring box to the inverter was challenging because the supplied screws (M6x12) were not long enough to thread into the corresponding threaded holes on the inverter without first compressing the neoprene gasket. Having screws a few millimeters longer will make this step much easier.
    e. In general, the provided screws should be a bit longer in order to make assembly easier, especially were a neoprene gasket is involved.
    f. There is not very much space in the wiring box between the knockout holes in the bottom of the inverter and the wire terminals. This is especially true if you are using the larger recommended conductor size.
2. Installation of shade plate
    a. There are some screws protruding from the top of the inverter that do not have a corresponding clearance hole on the Shade Plate. This issue resulted in the shade cover resting on the tops of the aforementioned screw heads as opposed to on the inverter case.
    b. The brackets did not have the correct hole spacing to line up with the holes for the screws that hold the wiring box to the inverter.
    c. The provided screws (as provided with the inverter, as the Shade Plate was not provided with screws) were certainly not long enough to accommodate the Shade Plate.
    d. It appears that the part of the shade cover that covers the LCD screen on the wiring box was intended to be easily removable, but one must remove the entire shade cover to separate the two parts of the cover. This is not ideal.

About Us

For companies developing PV products and projects, PV Evolution Labs (PVEL) is the premier solar panel performance and reliability testing lab. We provide secure, expert testing and validation services so you can be confident that you're making intelligent decisions based on the most reliable data.

PVEL is founded on the principle that understanding solar panel aging behavior through testing is a fundamental aspect of safety, cost reduction, and reliability – all of which are imperative to the growth, health, and evolution of the solar industry. PVEL is committed to increasing photovoltaic product quality while reducing product time to market.

Our dedicated environmental, mechanical, and electrical testing systems are designed specifically for the flat plate PV module form factor. Utilizing dedicated characterization systems ensures optimal data quality and repeatability. PVEL's calibrated equipment base is closely maintained to ensure optimal availability and reliability. Our specialized services are available for product and process qualification, raw material and supplier evaluation, ongoing reliability testing (ORT), risk assessment, lot acceptance, energy yield evaluation, and more.

The PVEL team possesses unparalleled expertise in test and measurement techniques for semiconductor devices and PV modules. Our highly qualified technical staff is dedicated to serving the needs of the solar industry with a commitment to excellence in test quality and customer service. PVEL aims to collaborate with our clients throughout the development cycle. By working with you from start to finish, we ensure the highest quality product with a faster time to market.

Our mission at PVEL is to facilitate the dramatic growth of the North American solar industry.