FY15 Final Technical Report for DOE SunShot
Sandia National Laboratories*
Agreement # 24372, 25538, 25539
PV Regional Test Centers

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Introduction

Sandia National Laboratories (Sandia) manages four of the five PV Regional Test Centers (RTCs). This report reviews accomplishments made by the four Sandia-managed RTCs during FY2015 (October 1, 2014 to September 30, 2015) as well as some programmatic improvements that apply to all five sites. The report is structured by Site first then by Partner within each site followed by the Current and Potential Partner summary table, the New Business Process, and finally the Plan for FY16 and beyond. Since no official SOPO was ever agreed to for FY15, this report does not include reporting on specific milestones and go/no-go decisions.

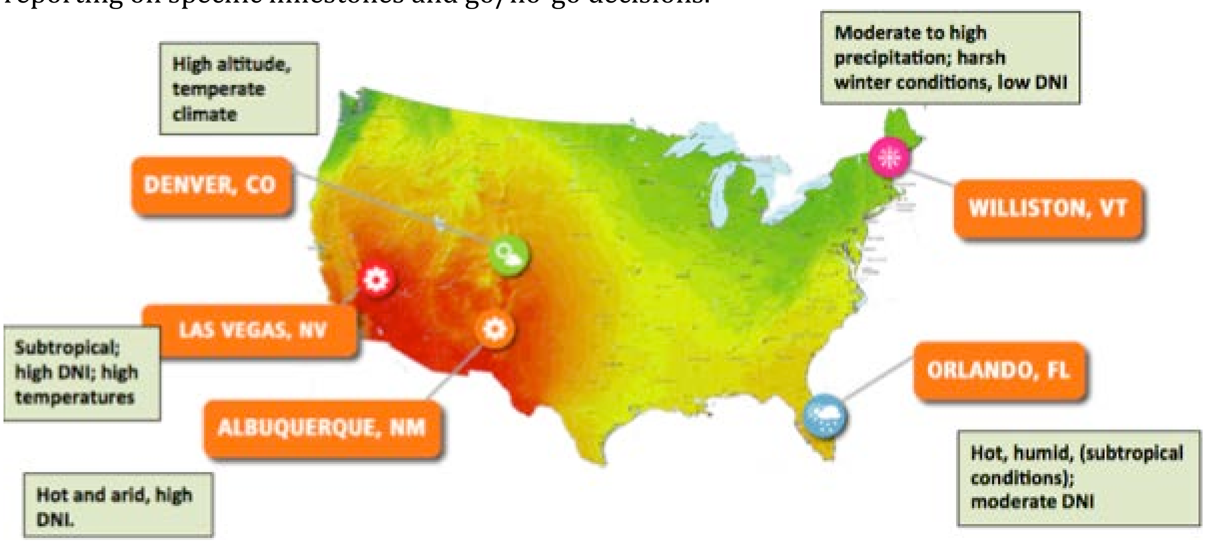

Figure 1. Locations of the five Regional Test Centers; Sandia manages the sits in New Mexico, Florida, Vermont and Nevada.

Background

The RTCs validate new solar technologies and system configurations, demonstrating performance and reliability under field conditions over time. There are five sites representing a range of climate conditions (NREL manages the Colorado site). The RTCs provide technical assistance to solar companies in the US. This program has shifted its focus, along with the industry, from validation of large systems to more targeted studies of small systems designed to compare sub-arrays of different module technologies. In addition, the RTCs are actively seeking partners from both module manufacturers and balance-of-systems producers.

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The RTC Program has made significant advances in FY15, which include reducing costs for system installations by implementing a more streamlined design and construction process, site upgrades that allow for ballasted systems in New Mexico and Nevada and the installation of "Fast Track" racking. The "Fast Track" racks, as the name implies, are preconstructed, fixed-tilt racks that can be configured to accommodate any standard flat plate module technology and will therefore speed the installation of new partner systems. The Sandia team has also been working to increase program agility by instating a more effective application process, and replacing CRADAs with MOUs, which take less time to complete. We have also increased the value of the RTCs to industry and to the research community by adding additional data collection capabilities, such as baseline systems for PV output and soiling rates, at each RTC.

FY15 Installations

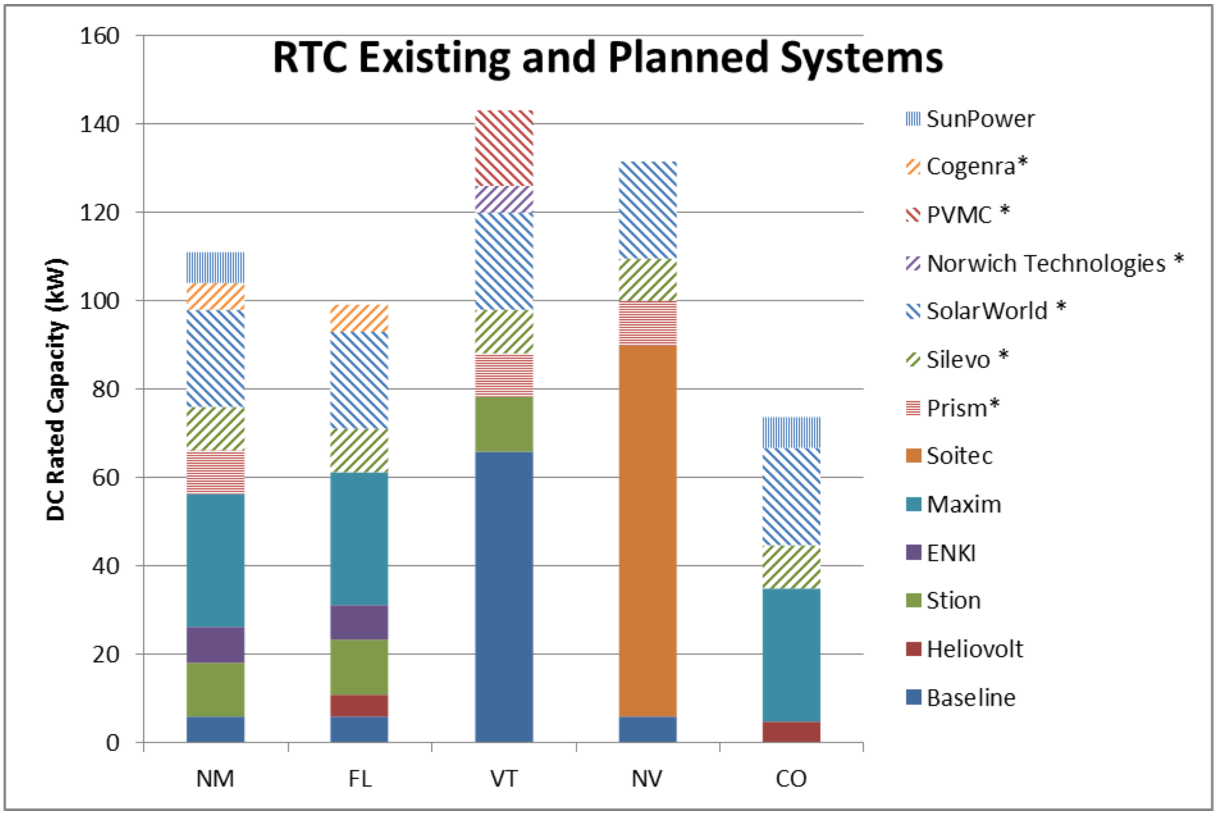

Figure 2. Overview of the installed and planned PV capacity at the DOE RTCs; total number of KWs installed as of the end of FY15 across the five RTC sites is approximately 320 kW. If all planned partners install, the RTCs will have at least 530 kW installed.

FY15 RTC Site Accomplishments

This section describes the accomplishments made in FY15 at each of the RTC sites. It does not describe specific partner installations at these sites, which are covered in the following section.

New Mexico RTC-North

The New Mexico RTC site was split into two facilities in FY14, with the creation of a "RTC-North" site, co-located with Sandia's Photovoltaic Systems Evaluation Laboratory (PSEL), which has onsite testing capabilities and technical expertise. The new site allows for less expensive and faster installations of smaller (<50 kW) systems, complementing the "RTC-South" site at the National Solar Thermal Test Facility. The RTC-South site continues to be available for partner installations between 50 kW and 250 kW. The infrastructure at PSEL required some site upgrades (including installation of a step-up transformer and ground preparation), which were completed in FY14.

Figure 3. Ground preparations for the New Mexico RTC-North site, which is co-located with Sandia's PSEL, were completed in early FY15.

In FY15, pre-work for electrical upgrades, including an electrical panel (MDP2) began October 9th, equipment arrived October 19th, and work was completed on December 17th, 2014. The cost of this upgrade was covered by Sandia facilities (overhead); not the RTC project.

Later in FY15, Sandia instigated its second infrastructure upgrade: the installation of about 700 linear feet of fixed-tilt racking referred to as the "Fast Track" rack. The rack consists of 10 rows of 35° fixed-tilt racks mounted on large "bin blocks" used as ballast. The bin blocks, which are 2x2x6 ft., are made from concrete that is left over from area construction projects and are sold for less than $50 each, including delivery. This design is ideal for the Sandia site because it is economical, requires no ground penetrations (ground penetrations require permits from the Air Force[†]), and allow easy removal at the end of the project. Another advantage to the Fast Track design is that the entire rack shares a plane-of-array (POA) irradiance monitoring system, allowing all the PV systems installed on the rack to read POA irradiance from a single datalogger via Modbus communications.

[†] Sandia is located on Kirtland Air Force Base in Albuquerque, New Mexico.

Figure 4. Site plan for the New Mexico RTC-South site showing the locations of various systems located at the PSEL.

Florida RTC

The infrastructure at the Florida RTC site located at the Florida Solar Energy Center (FSEC) has been completed and is available to receive partner installations up to 300kW. RTC infrastructure includes ground and site preparation, network infrastructure, permitting, etc. A one-year contract extension is currently being negotiated to fund FSEC to continue to maintain the site and install partners through the end of FY16.

During FY15, FSEC began installation of their Fast Track racking, which differs from the New Mexico design in that racks are mounted into the ground using driven piles rather than ballast blocks. Most of the mechanical work was completed by the end of FY15, leaving only the electrical interconnect and irradiance monitoring systems to be installed in early FY16.

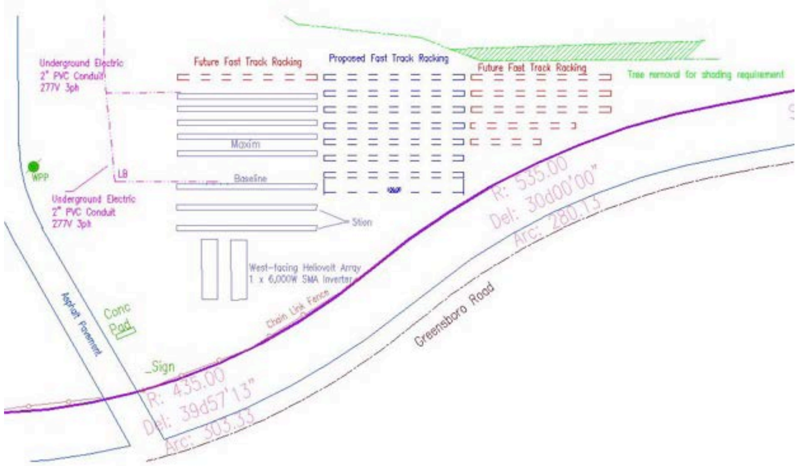

Figure 5. Site plan for the Florida RTC. The locations of the Fast Track racking is shown as “Proposed Fast Track Racking” in the center of the figure. “Future” locations are available in case expansion is needed.

A baseline system, using c-Si modules identical to those at the other RTCs, was completed in November 2014. The retrofit to replace one of the inverters and install a 240 kVa transformer was started, but not completed by the end of the FY15.

Figure 6. Current RTC systems installed at the Florida RTC. Does not include the ENKI project, which is located at a nearby site.

Nevada RTC

In FY15, the major activity at the Nevada RTC focused on the removal of three non-operational Amonix trackers to expand the site and allow for a significant increase in future RTC installations. The removal, which required the legal approval and oversight of the Southern Nevada Water Authority, was completed in FY15.

Figure 7. Left: Two Amonix trackers in foreground before removal. Right: site after all three trackers were removed and the site graded.

The baseline system planned for installation in Nevada in FY15 was delayed by the decision to remove the Amonix trackers, which introduced administrative and procurement complexities, but is now nearing completion and will be commissioned in early FY16. Sandia has designed a Fast

Track rack for the Nevada site and is now working with procurement to place a contract with a local installation company. Sandia will report on the success of this activity in FY16.

Throughout FY15, the University of Nevada, Las Vegas (UNLV) provided technical support for the Nevada RTC site, overseeing the site expansion and providing operation and maintenance for the 84-kW Soitec system. UNLV will continue to provide technical support in FY16, including the management of new installations, troubleshooting any technical issues that arise, and providing ongoing maintenance, including regular cleaning of irradiance sensors.

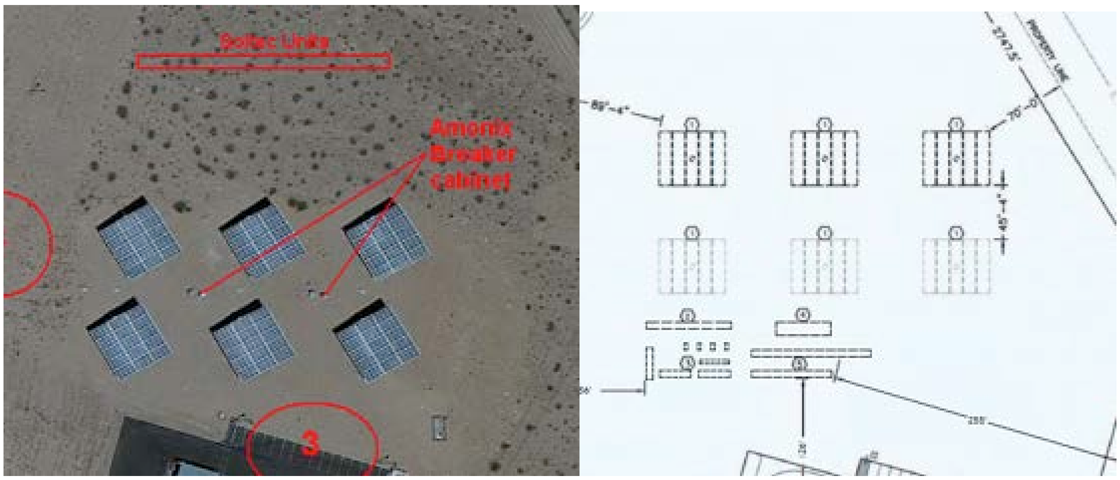

Figure 8. Aerial view of the Nevada RTC. Image (left) depicts the site prior to the removal of the three Amonix trackers; Image (right) shows a conceptual layout for the baseline array and partner installations.

Figure 9. Nearly complete 6-kW baseline system (*see red arrow*) at the Nevada RTC, Amonix and Soitec trackers are to the north.

Vermont RTC

The Vermont RTC base build, including electrical and communications infrastructures, weather station, a 6-kW baseline array, and a soiling station is complete and generating data. To ensure the continuity of operations, Sandia has placed two operations and maintenance contracts for the Vermont RTC: one with Global Foundries (formerly IBM) to cover basic site maintenance and installation support; the other with E&S Electric to provide technical and trouble-shooting support, including sensor cleaning, module replacement and current-voltage testing.

The baseline array, while operational, is scheduled to have one of its inverters (from Fronius) replaced and a transformer installed in early FY16. Until then, as described earlier in this report, the data is not being released to the public. This system was commissioned in August 2014; the 60 kW c-Si system in the next row north (see figure 10) was commissioned in September 2014.

Figure 10. View of the PV arrays installed at the Vermont RTC as of the end of FY15. Array in back row is the 60-kW c-Si array. In the front row is the 6-kW baseline system in the foreground and the Stion systems in the background.

Multi-Site Baseline Systems

In FY15, the RTCs finished installing baseline arrays in New Mexico, Florida, and Vermont. The 6kW systems are each comprised of two 3kW sub systems of US-made mono-crystalline flat-plate modules, utilizing two Fronius IG Plus Advanced 3.0-1 UNI inverters. These systems serve a dual purpose: 1) they generate performance data against which the performance of partner systems and new module technologies can be compared and 2) they are not proprietary systems so the data they produce is publically available.

The three baseline systems installed to date are located in New Mexico (208 V), Florida (277 V), and Vermont (277 V). An additional system is close to completion in Nevada (277 V) and will be commissioned by the end of November 2015.

Performance Issues Discovered with the Baseline Systems

The RTCs measure performance every five seconds and record 1-minute averages of these measurements. It was observed that the two systems in Florida and Vermont exhibited regular and frequent dropouts lasting five minutes in duration. The system in New Mexico does not display this behavior. The two figures below show examples from Florida. The first shows a nearly clear day and the second shows a partly cloudy day. In both cases the dropouts occur when irradiance is low (approximately 200-300 W/m^2).

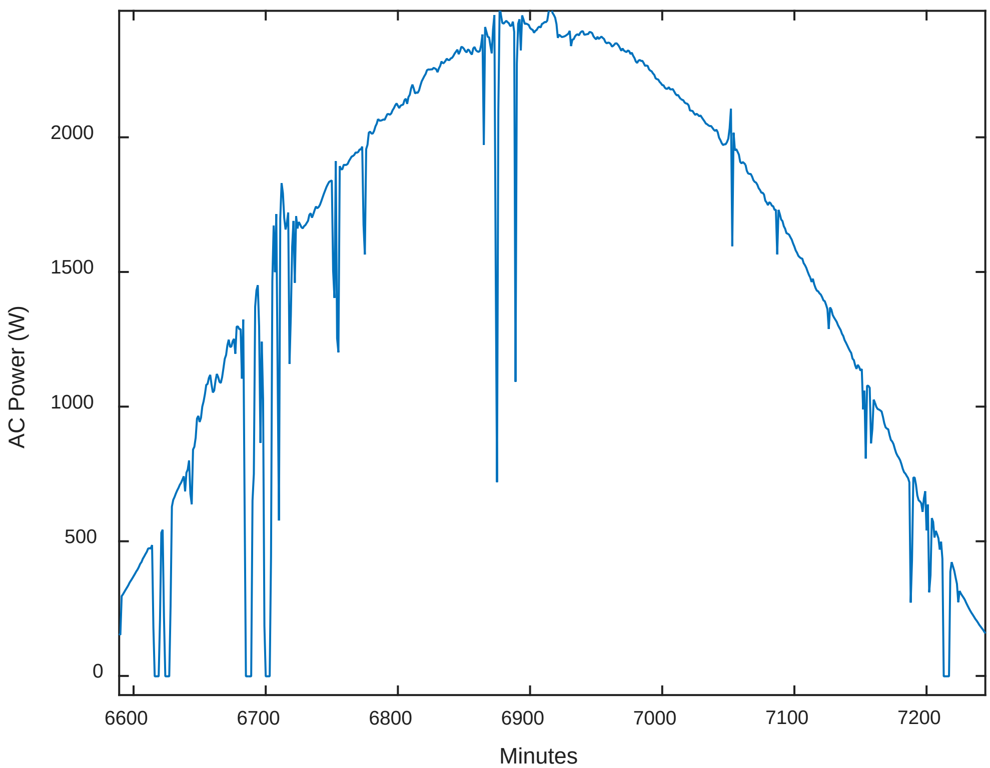

Figure 11. Example AC output from inverter on a nearly clear day in Florida, with minimal cloud cover.

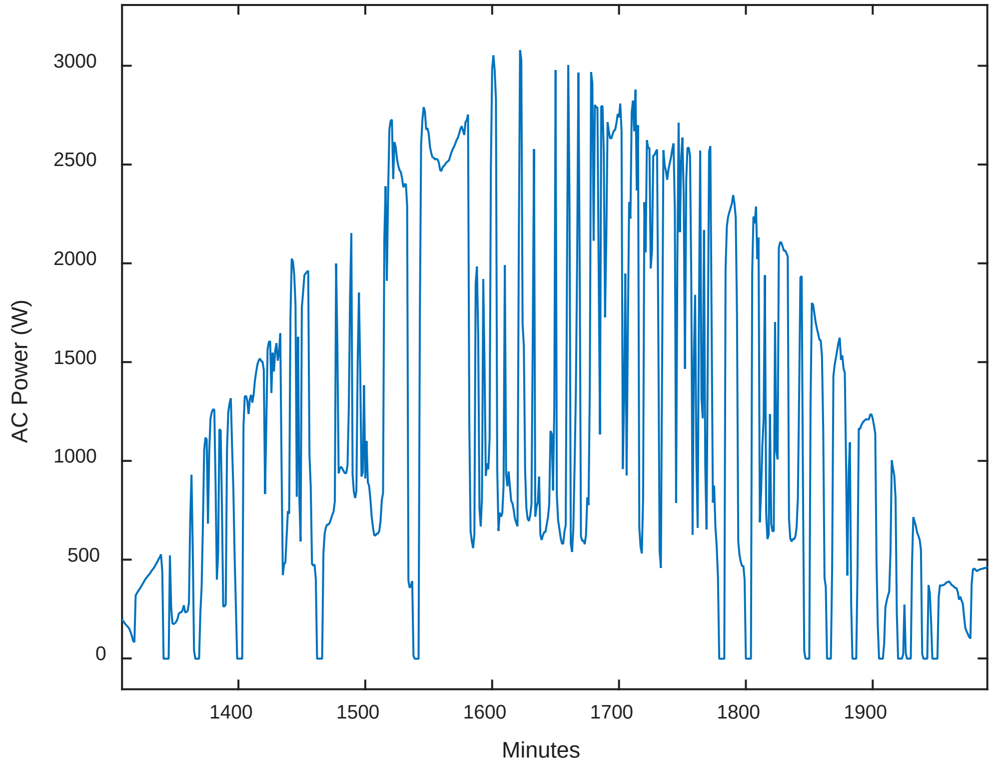

Figure 12. Example AC output from inverter on a variable day in Florida, when clouds caused rapid drop-offs in power throughout the afternoon.

The RTCs contacted Fronius to alert them of this behavior and have been working with them to try and figure out what is causing these dropouts. Initial troubleshooting focused on removing noise on the AC circuits to which these systems were connected. None of the suggested solutions fixed the problem.

On June 10, 2015, Sandia removed one of the inverters at the New Mexico site and brought it to the Distributed Energy Test Lab for more detailed evaluation. The inverter was connected to Sandia's PV and AC Grid simulators and run through an irradiance profile defined by EN 50530-2010 standard, which is widely used to measure inverter MPPT efficiency (Figure 13). This profile was run several times at both 208 and 277 V grid connections.

The results of these lab tests matched the behavior seen in the field. The inverter connected at 277V experienced dropouts at lower irradiance values (Figure 14), while the 208 V tests did not result in any dropouts (Figure 15). In addition, this inverter appears to have trouble with maintaining maximum power point tracking control, especially when irradiance is increasing; this was seen at both 208 and 277 V operations.

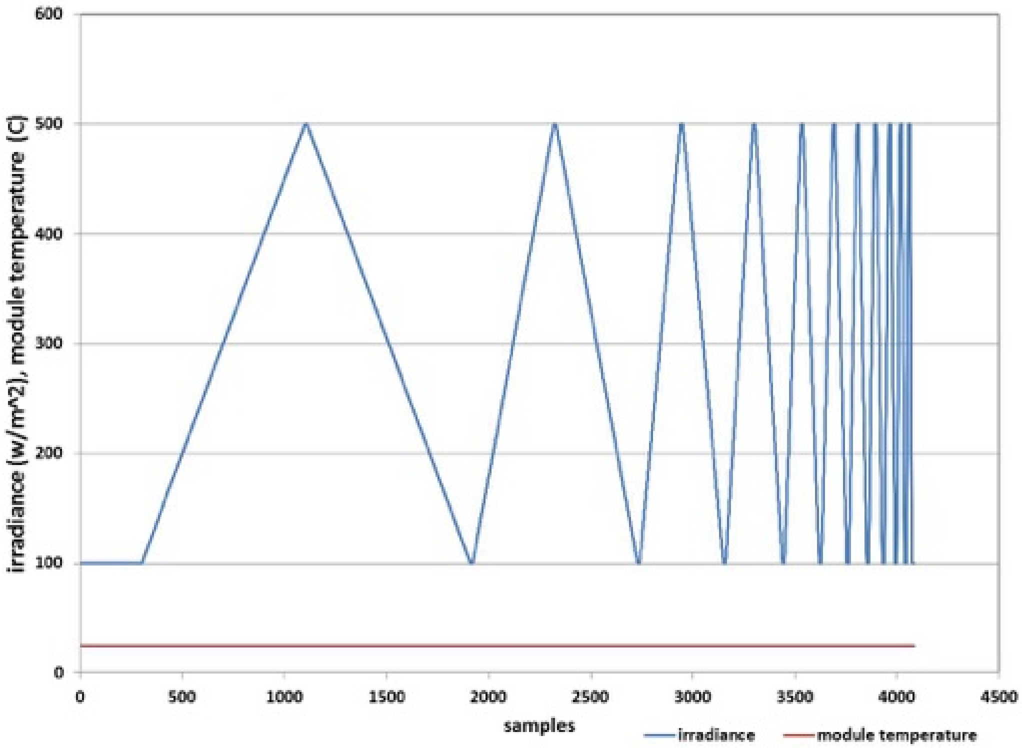

Figure 13. EN50530 10-50 Irradiance Profile

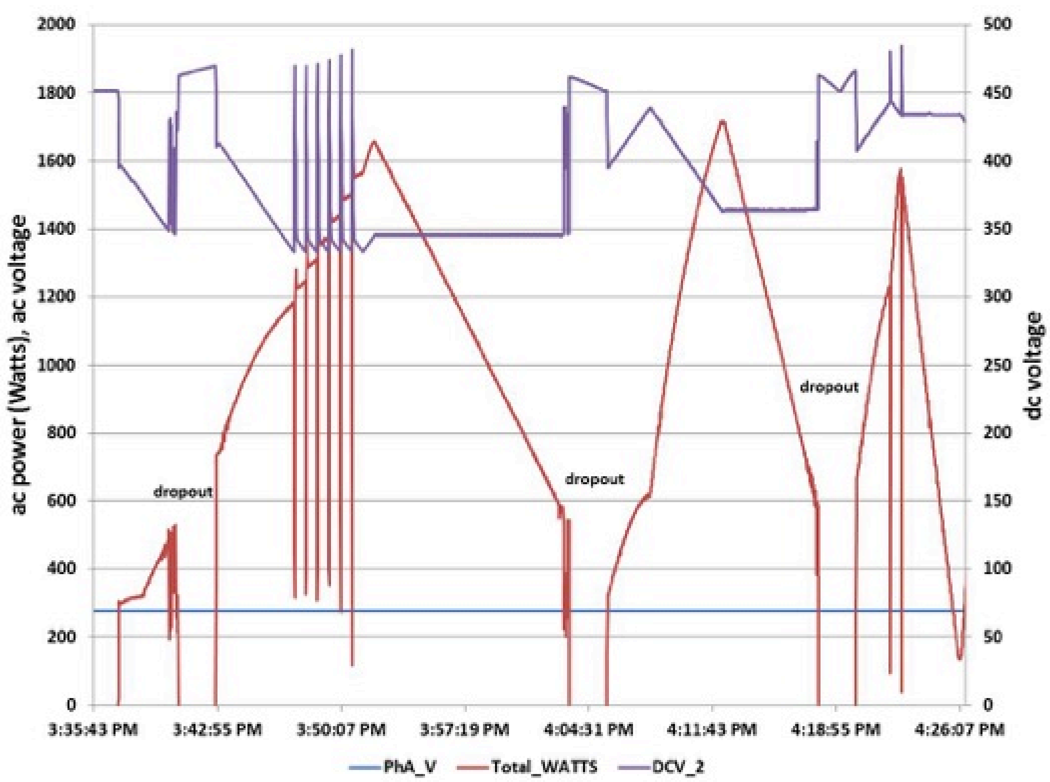

Figure 14. Inverter configured to 277 VL-N and operating at varying low power levels.

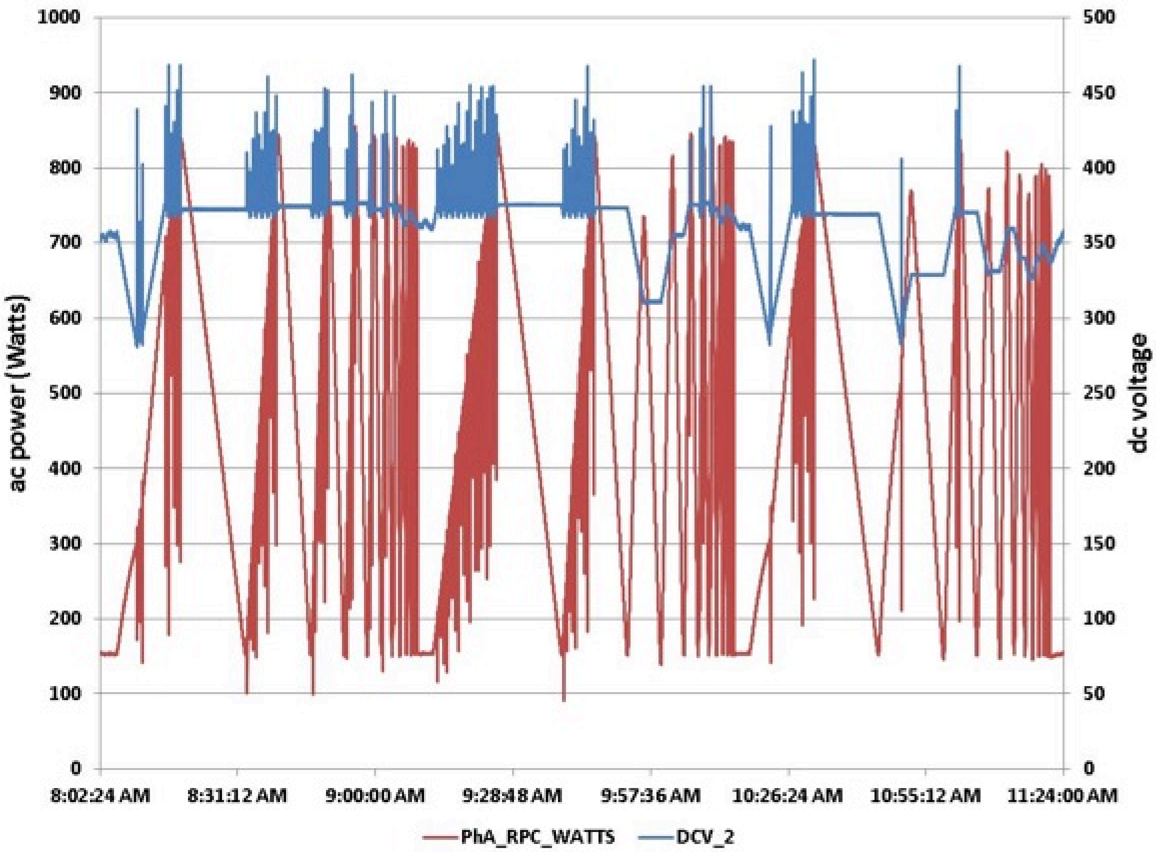

Figure 15. Inverter configured for 208L-L operation—showing MPPT issues but no dropouts

The MPPT problems during increasing irradiance in Figure 14 are evident from both the rapid power fluctuations and the curved shape of the smooth sections of the power curve during increasing irradiance periods. "True" MPPT power should have the same "V" shape as the irradiance profile, since temperature is not varying in the simulator profile. It is more difficult to see any curvature in Figure 15, but the rapid fluctuations are numerous on the up-ramp periods. Sandia has shared these results with Fronius, who agreed that Sandia had identified a previously undiagnosed problem.

The effect of these dropouts and MPPT issues made Sandia reluctant to make the performance data from the baseline systems publicly available. In response to these findings, the RTCs made the following changes, which were started in FY15 and continue into FY16:

1. One Fronius inverter on each of the baseline systems would be replaced with an SMA inverter.
2. Small transformers will be installed at each of the RTCs to allow the baseline systems to lower the connecting voltage from 277V to 240V AC, which is the typical interconnection voltage for small, residential-sized inverters.

By the end of FY15, the New Mexico RTC's baseline system was retrofitted with both a new transformer and a new SMA inverter and the system operations are appear normal following the retrofit. Similar retrofits are underway at the other sites.

RTC Soiling Stations

Soiling stations have been installed at the New Mexico, Florida, Vermont, and Colorado RTC sites during FY15. These stations include a series of ten split reference cells that are attached at a variety of tilt angles. Approximately twice per week, one half of each cell is cleaned while allowing the other half to collect dust and dirt at a natural rate. The short circuit current is measured on both halves of each cell and the change in the ratio of the dirty to the clean side after each cleaning event can be used to quantify the soiling rate on the dirty side. When there is sufficient rain, both sides are cleaned and the ratios are reset. Below is a figure of the soiling station at the Vermont RTC.

Figure 16. Soiling station at the VR RTC is measuring the effect of particulate accumulation on the energy output of split reference cells set at different tilt angles. The data logger *(grey box to the right*) is powered by the module mounted on the vertical post.

Initial data from the RTC sites is being analyzed and Sandia's preliminary finding suggests there is an unforeseen effect of angle of incidence on the split reference cells that is affecting the data analysis. We noted that when the ratio of dirty to clean Isc was plotted over a full clear day when no cleaning was performed this ratio increased about 4% during daylight hours. This result does not appear to be related to any soiling phenomena but instead seems to be related to the orientation of the split reference cells in relation the Sun path across the sky. We suspect that the single glass cover on the split cell is channeling light preferentially to one side the device depending on the angle of the sunlight. To test this theory, we rotated two of the cells 90° so that instead of the two half cells being side by side they were one on top of the other. The resulting Isc ratios (shown below) for a clear day show that the rotation resulted in a much flatter daily profile. Sandia is investigating this effect using a ray tracing model to understand the phenomenon and plans to report results at IEEE PVSC in the summer. In the meantime, Sandia plans to rotate the cells at each of the RTCs to improve data quality.

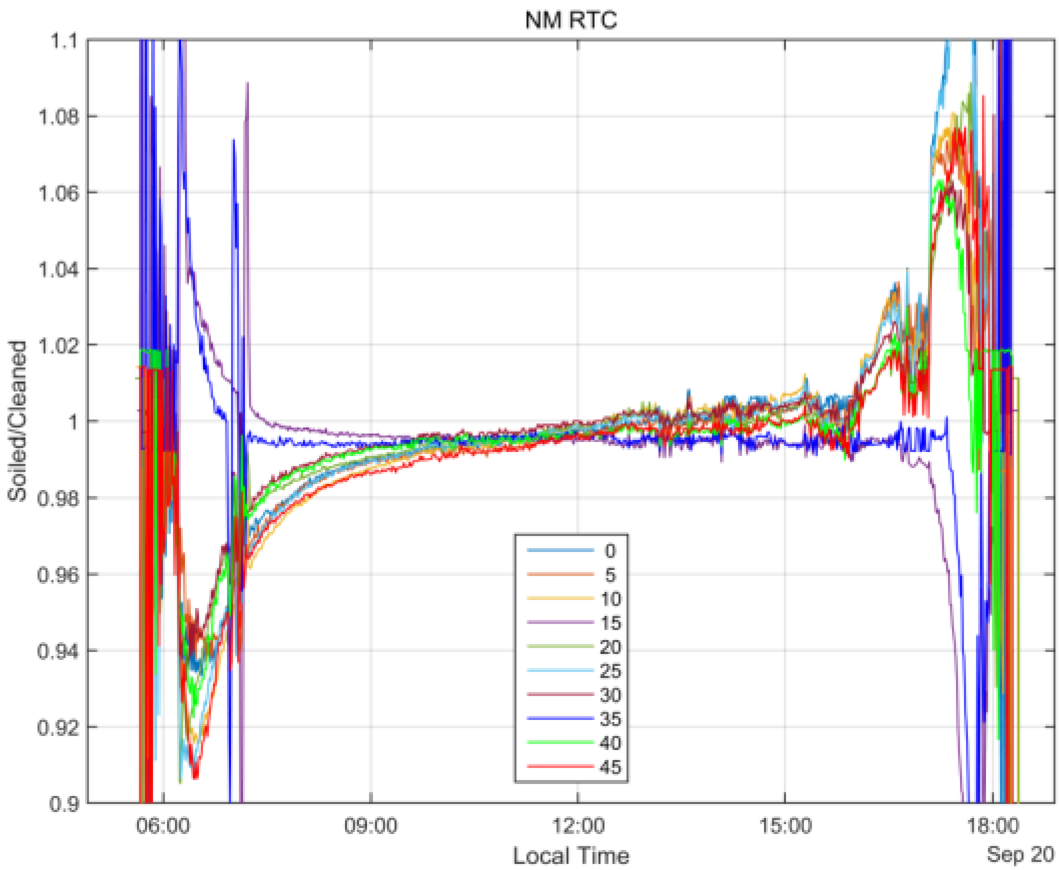

Figure 17. Ratios of Isc measured on dirty and clean sides of split reference cells show that for most of these instruments the ratios tend to increase over the day (ignore the noise present at the beginning and end of the day). Two of the cells were rotated 90° and they show a much flatter profile during the day.

RTC Partner Updates

Heliovolt – Identical 5kW, 10° tilt, west-facing systems are currently being monitoring in Colorado, and Florida. Because Heliovolt is no longer in business, the system previously installed in New Mexico was decommissioned in FY15 to save ongoing site fees of over $12K per year. Heliovolt formally abandoned its equipment, allowing Sandia to take possession of it. The Heliovolt systems in Florida and Colorado will remain operational as long as O&M costs are minimal. Data from these systems, as well as the modules from the New Mexico system, will inform a recently funded DOE PV research study at Sandia to investigate CIGS performance and reliability. This new project runs from FY16-18.

Soitec – A three-tracker concentrating photovoltaic (CPV) system totaling 84 kW was installed at the Nevada RTC in March 2014. Data from the system is transmitted daily to Sandia, where it is automatically stored in the PV Data Management System (PVDMS) and available for analysis. During this 20-month period, the trackers have had various technical issues, including bent encoder shafts and multiple popped inverter fuses, but Soitec has worked with UNLV to fix those problems and is now confident the systems are structurally sound.

During FY15, however, Soitec announced that it was selling its CPV business and no longer had interest in the trackers or their data. Soitec, Sandia, DOE and UNLV have discussed the possibility of keeping the systems operational for a few more years or until they are deemed to have no operational or research value. Although a transition plan has yet to be finalized, all parties are in favor of keeping the systems operating under the ownership of UNLV. The RTCs would cover the costs for routine O&M; Soitec would supply enough spare parts for the next 5-6 years as well as some additional O&M training to UNLV; and UNLV would agree to remove the systems, at no cost to SNWA when UNLV no longer sees value in their continued operation.


Figure 18. Soitec trackers installed at the Nevada RTC.

Maxim Integrated – 40-kW systems were installed in Colorado, New Mexico, and Florida in FY14-15. The main purpose if this partnership is to quantify and validate the effectiveness of the Maxim Integrated dc-dc optimizer chips to provide energy gains from systems designed with row-to-row shading in order to fit more PV in less space. The systems are designed with variable row spacing and modules/strings with and without the Maxim chips installed. Performance comparisons between these strings are used for the validation. Unfortunately, these Maxim chips seem to generate a lot of high frequency RF noise which interferes with standard PV monitoring systems. Much of the effort at New Mexico and Florida in FY15 was spent trying different signal isolation approaches to attempt to isolate and filter out this noise. Sandia, NREL, FSEC, and Maxim have been working to troubleshoot problems. New equipment has been installed with the intent of improving the quality of the signals. As of the end of FY15, the search for the best approach was still ongoing.

New Mexico – The New Mexico system was installed in the summer of 2015, but official commissioning has been delayed due to the difficulties described above.

Figure 19. Maxim Integrated array in New Mexico.

Figure 20. Testing of intentional row-to-row shading on the back row of Maxim's RTC array in New Mexico began in October 2015.

Florida: Maxim system in Florida was installed in FY15. Florida has been the primary laboratory for figuring out how to solve the monitoring problems with this system.

Figure 21. Maxim integrated array in Florida.

Stion – A 12-kW system, divided into two sub-arrays, was installed at the New Mexico, Florida, and Vermont RTCs during FY15. Stion's objective is to validate and compare the performance and reliability of its framed versus frameless modules in multiple climates, especially in Florida and Vermont, where high levels of humidity and precipitation could impact the integrity of the edge seal on their frameless modules. Sandia provided Stion with a baseline-characterization report and has been sending Stion data reports, with some preliminary analysis, since June 2015.

In the months since the Stion systems have been installed, Sandia has observed a high rate of module failure, correlated with cracking. Sandia prepared and delivered a report to Stion detailing when and where broken modules were discovered[‡]. This report also provided thermal and electroluminescence images of module hot spots that may have developed following moisture ingress into the module through the cracked glass. The table below lists the number of cracked modules of each type at each site. Cracked modules were discovered at all three sites and have been removed and replaced. A subset of the most badly damaged modules has been sent to Sandia for further analysis.

Post-Installation Module Failures		
RTC Site	STO Modules (Framed)	STL Modules (Frameless)
New Mexico	2	1
Florida	0	1
Vermont	5	0

[‡] Burnham, et al., 2015, "Early Failure of Stion STO-140 and STL140 Modules at the New Mexico, Florida, and Vermont Regional Test Centers, Sandia RTC Report 342766.

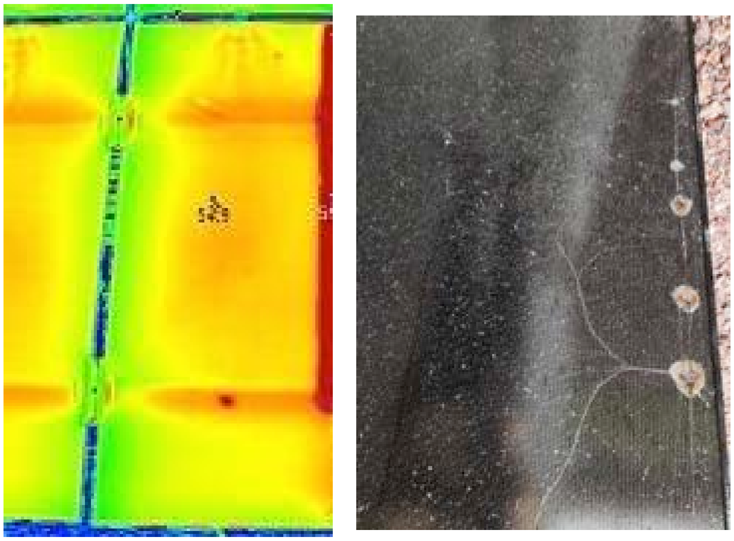

Figure 22. Thermal image (*left*) showing a hot spot (*vertical red streak*) that was taken of a module with a crack along a long edge of the module. Visible image (*right*) of a module that cracked and then developed hot spots.

Figure 23. Sandia takes IR images of the Stion modules at the Vermont RTC.

New Mexico: This system was completed in March 2015. Commissioning of the system was finished in April.[§] The first uninterrupted month of data began in May 2015.

[§] Carmignani, C., 2015, "Regional Test Center (RTC) Commissioning Report: Stion 12.32 kWDC Fixed Latitude Tilt Ground Mounted Photovoltaic System" Sandia RTC Report SAND2015-8096.

Figure 24. Stion system in New Mexico. Framed subarray in the foreground and frameless in the background.

Florida: This system was completed in March 2015.

Vermont: This system was completed and commissioned in November, 2014. This system experienced a lot of snow during the winter of 2014-15 and by spring six modules had cracked and needed to be replaced. It is not yet clear what caused the module cracking.

Figure 25. Snow nearly covered the Stion array during the winter of 2014-15.

ENKI - 8kW systems in New Mexico and Florida testing the effectiveness of anti-reflection and soiling coatings compared with uncoated modules. This partner was brought into the RTC after already installing a system in Florida. ENKI is currently doing the analysis of the data delivered to them by the RTCs.

Figure 26. New Mexico: ENKI system was installed in August and is operational.

Figure 27. ENKI system in Florida.

Prism Solar - ~9-kW systems are being installed in New Mexico, Vermont, and Nevada. Prism manufactures bifacial modules and has asked Sandia to validate the bifacial gain as a function of tilt angle, and other array parameters. Developing a validation plan and designing the system has been complicated, given the number of small sub-arrays at multiple tilt angles and orientations, against different substrates and the need to measure the performance of both bi- and mono-facial modules, which also require module level monitoring using microinverters and independent DC monitoring. Because of the complexity of the systems, Sandia proposed installing in New Mexico first, to iron out the details, which include mounting, designing an optimal layout, and developing a n effective monitoring system. Once these issues are finalized, external contractors will install in Vermont and Nevada. The New Mexico system was almost completed in FY15 but the racking supplier sent the wrong parts to New Mexico. The system is now scheduled to be installed in early FY16.

Figure 28. Portion of the Prism installation in New Mexico. Some of the racks are placed on a highly reflective white background to enhance the light available on the back of the arrays.

Figure 29. Prism array in New Mexico. Vertical modules oriented E-W and N-S are included in the test array.

Photovoltaic Manufacturers Consortium (PVMC) is installing five different systems representing four CIGS module manufacturers at the Vermont RTC, adjacent to the Stion CIGS arrays. PVMC is installing the arrays and the monitoring systems, with guidance and technical support from Sandia. Sandia has provided PVMC access to the site, reviewed the design and provided detailed specifications for the monitoring systems. The five arrays will be commissioned in early FY16, in accordance with the RTC commissioning procedure.

Figure 30. PVMC arrays installed--but not yet commissioned--at the Vermont RTC. Five of the six CIGS arrays (including Stion) are visible in the first row above (see labels).

Figure 31. Global Solar CIGS modules at the Vermont RTC that are being installed by PVMC.

Renewable NRG Systems is a Vermont-based company that designs (and manufacturers locally) a turnkey solar resource assessment system with, weather and irradiance instruments and integrated data acquisition and communications capabilities. Sandia conducted a validation study of the installation at the Vermont RTC, timing the process and collecting observational data on the ease-of-installation and the overall quality of the turnkey system from the perspective of a standardized, integrated system ready to deploy around the world. Sandia is also collecting data generated by the system in order to compare the accuracy of the meteorological data with the data provided by the Vermont RTC weather station

The solar resource assessment system was installed by two student interns at Global Foundries who had no former experience installing meteorological instrumentation and were therefore considered representative of likely installers around the world. The installation was witnessed and analyzed by two observers from an industrial engineering perspective. The results and Sandia's analysis, including specific suggestions for improvement, will be delivered as a formal report to RNRG in early FY16. This report will fulfill the first objective of the project. The analysis of the weather data generated by the system will begin in FY16.

Figure 32. Solar resource assessment system installed at the Vermont RTC. The data logger (white box on tower) is powered by the solar module; irradiance and wind instruments are mounted at the top of the tower on booms; the rain gauge is to the right.

Norwich Technologies/Chilicon Power/SolarWorld is the first multiple-company, all-American partnership for the RTCs. Norwich Technologies has developed a modular racking solution, called EZ-PV, which is pre-assembled at a plant in White River Junction, Vermont and then transported to a job site, where it can be installed and fully operational in less than a day. Chilicon is a start-up company manufacturing microinverters in California interested in gaining bankability data to enable market expansion. SolarWorld is a US module manufacturer interested in the comparative performance of two module types (mono- and poly-crystalline) on a west-facing roof. Each partner has donated equipment and time; together they have collaborated on a system design that Norwich will implement. Sandia will provide the monitoring system, collecting AC data from sensors and current transformers, and DC data from the Chilicon micro-inverters. The system is scheduled for installation in early FY16.

Figure 33. The Norwich/Chilicon/SolarWorld rooftop PV system will be installed on the roof of the Vermont RTC equipment shed.

Figure 34. Norwich Technologies reinforces the rafters in preparation for the EZ-PV installation.

Future Projects

Cogenra plans to install two high efficiency c-Si systems in New Mexico and Florida. This company originally applied to the RTC with a hybrid CPV system that heated water. The company then changed their focus to a high efficiency c-Si flat-plate module technology, which the company claims has set new module efficiency records. With its validation plan almost finalized, Cogenra expects to ship modules to the New Mexico RTC in early FY16.

SolarWorld manufactures multiple cell technologies and is interested in comparing the performance of their Mono-PERC bifacial and polycrystalline cell technologies in a variety of climates. They plan to install four arrays at each of the five RTC sites. Changes made by SolarWorld to the technical design has delayed installation until early FY16. At the end of FY15, Josh Stein and Bruce King visited the main SolarWorld production facility in Freiberg, Germany and meet with their laboratory director and project lead. This meeting has helped the parties to come to an agreed technical approach. Final details on the validation plan were awaiting SolarWorld review at the end of FY15 but no obstacles to an FY16 installation are anticipated.

Silevo, a module manufacturer owned by Solar City, plans to validate the performance of four of their module technologies, including bifacial modules, at all five RTC sites. Their systems will utilize the Fast Track racking at each site (except Colorado). By the end of FY15 the validation plan was nearly complete but still awaiting concurrence from Silevo. System installation is planned to begin in New Mexico, Florida, and Colorado in early FY16, followed by Vermont and Nevada in mid- to late FY16.

SunPower is a module manufacturer accepted into the RTC program at the end of FY15. They want to validate the performance of a new series of bifacial modules in Colorado and New Mexico. Installation in New Mexico would utilize the Fast Track racking and is anticipated to be completed in FY16.

Solaflect is a Vermont-based company that makes a suspension dual-axis tracker for commercial/residential applications. The RTCs plan to work with Solaflect in FY16 to validate the performance of the system, specifically the tracking accuracy and effect of shading caused by the suspension wires on system performance. An initial tracker will be installed in Vermont, with a potential additional system to be installed in Nevada. The Vermont system installation date is not available yet. Partner has delayed the project.

Dynapower is a Vermont based company that has developed an advanced hybrid inverter technology they would like to validate at the Vermont RTC using the 60 kW PV system installed there. They have submitted a preliminary proposal. They still need to find a battery company that wants to partner with them before the RTCs can officially review their proposal.

CURRENT PARTNER SUMMARY

Partner	Technology	Sites	Innovations/opportunities
Heliovolt	Module	NM, FL, CO	CIGS performance validation. Company is out of business
Soitec	HCPV	NV	Detailed performance model development and validation. Company is leaving solar
Maxim	Module PE	CO, NM, FL	Validating module integrated PE to allow closer row spacing
Stion	Module	NM, FL, VT	Validating frameless, glass-glass modules in different climates
Cogenra	LCPV	NM	Company switched technologies to very high efficiency c-Si modules.
ENKI	Coatings	NM, FL	Incubator awardee. Invited to join RTCs. Comparison of performance between different coatings
PVMC	Consortium	VT	Working with CIGS and CIS manufactures. – Waiting on PVMC to install
Prism Solar	Bifacial module	NM, VT, NV	Detailed performance model development and validation (effect of tilt, azimuth, and albedo on performance gains for bifacial modules.
Renewable NRG Systems	Weather monitoring	VT	Validation of solar weather station (quality, installation, and O&M)
Silevo	Module	All sites	Validation of high efficiency c-Si mono and bifacial module technologies
Norwich Technologies/ Chilicon/SolarWorld	System	VT	Validation of EZ-PV system (installation study)
Dynapower / ES company	Inverter/battery system	VT	Validation of commercial scale hybrid inverter – Waiting on proposal
SolarWorld	PERC Modules	All Sites	Validation of 4 different module technologies (mono and bifacial)
SunPower	IBC Bifacial	NM, CO, VT(?)	Validation of bifacial performance gains in fixed tilt and tracked systems
Solaflect	Tracker	VT, NV(?)	Validation of novel 2-axis tracker. Waiting on proposal.

Site Weather and Irradiance Comparison for FY2015

The site locations for the RTCs were chosen to include a wide range of weather conditions important for PV performance and reliability. In this section we present measured weather data that illustrates the observed differences at the four Sandia managed RTC sites in FL2015 (October 2014 to September 2015). Below are some annual comparisons by month for the following:

- Global horizontal insolation
- Direct normal insolation
- Global horizontal diffuse fraction
- Average monthly temperature
- Average relative humidity

Some of the distinctive differences between sites include the wide range in irradiance between sites and the very low winter temperatures in Vermont and the very high summer temperatures in Nevada. Also worth noting is the significant difference in relative humidity between the sites with Florida and Vermont experiencing relatively high relative humidity compared with the other two sites. These and other climate differences influence the performance and reliability of PV systems hosted at the RTCs.

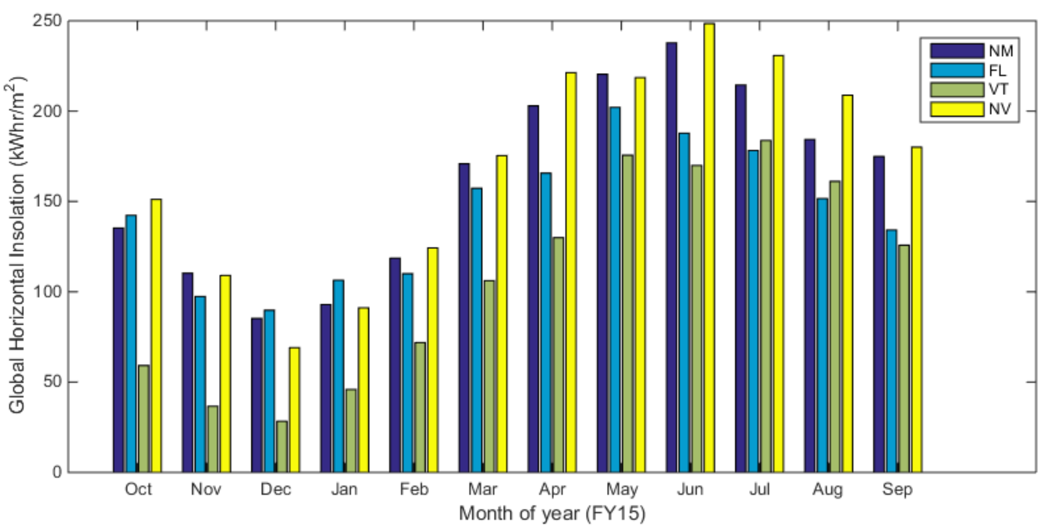

Figure 35. Global horizontal insolation by month for each of the four RTC sites managed by Sandia.

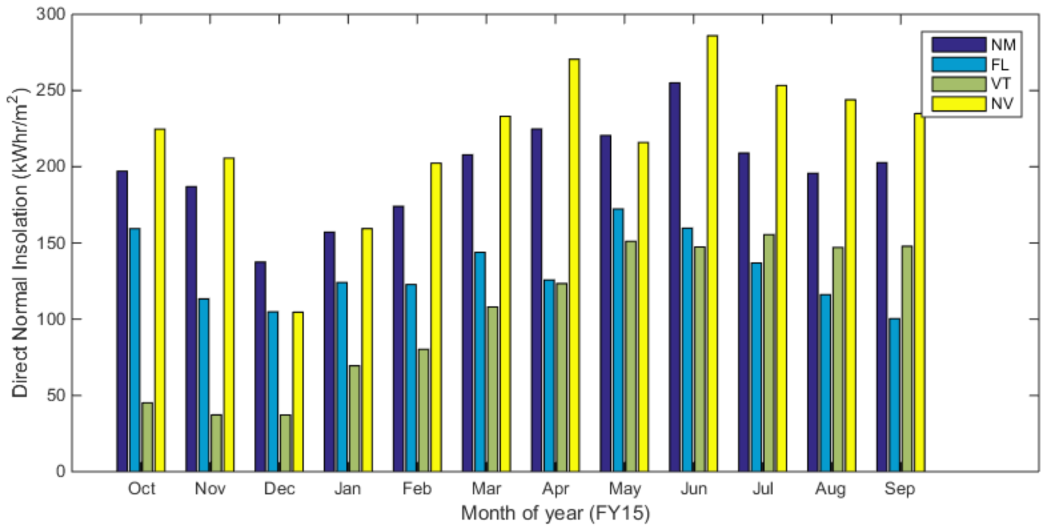

Figure 36. Direct normal insolation by month for each of the four RTC sites managed by Sandia.

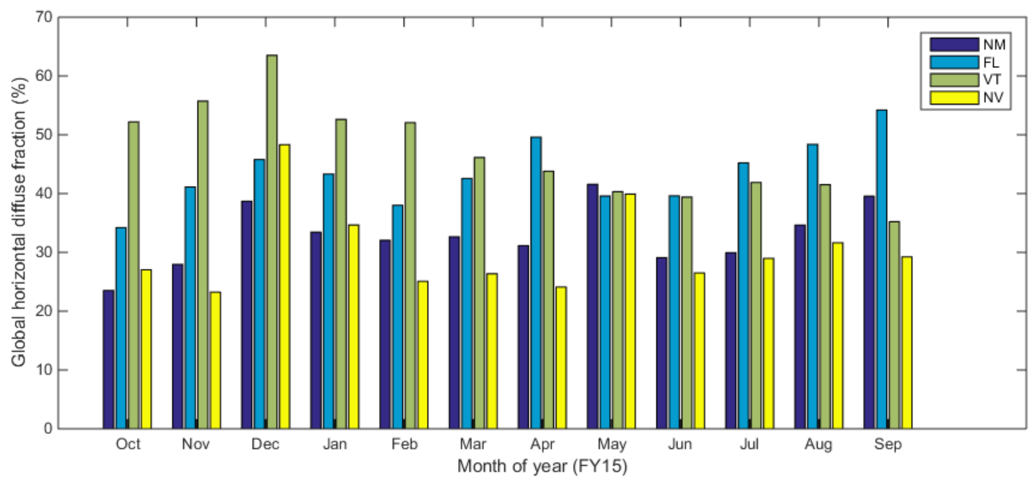

Figure 37. Global horizontal diffuse fraction by month for each of the four RTC sites managed by Sandia.

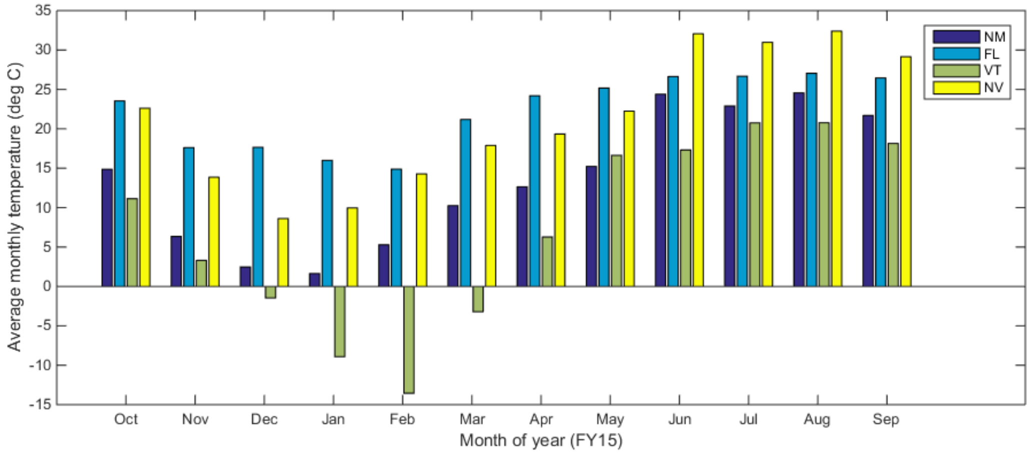

Figure 38. Average temperature by month for each of the four RTC sites managed by Sandia.

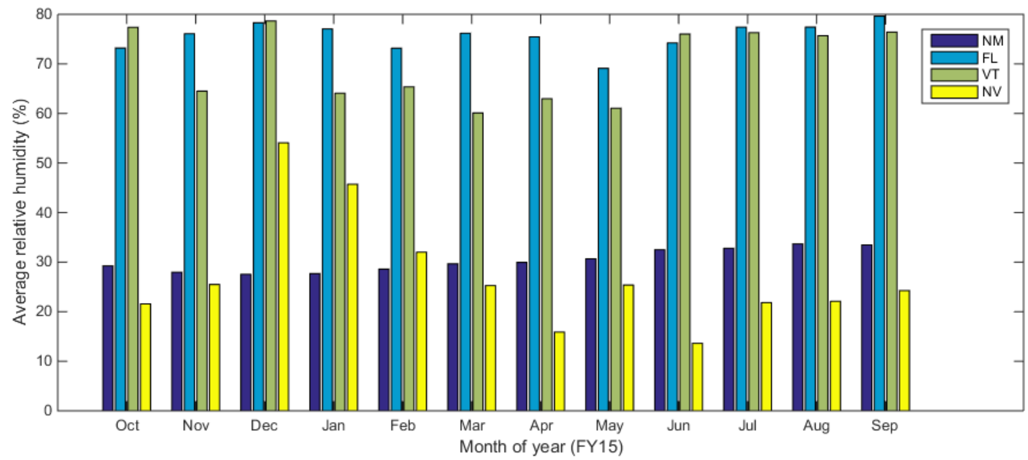

Figure 39. Average relative humidity by month for each of the four RTC sites managed by Sandia.

Baseline System Performance in New Mexico

The baseline system in NM began to be monitored in March 2015. The plot below shows the AC energy produced each month since from each of the 3 kW subsystems along with the data availability each month for system 1. The other baseline systems in Florida and Vermont experienced intermittent outages during this period which eventually were discovered to be caused by problems with the Fronius inverters when interconnected at 277V AC. In June, the inverter from system 2 in New Mexico was removed for testing in the lab and thus the energy output deviates from system 1 onwards, going to zero in July. This inverter was replaced early in FY16 with an SMA model and a transformer was installed to interconnect the system at 240V AC. Following an initial period of configuration, data availability from system 1 has been 100%. Due to the outages experienced at the other sites in FY15, we are not reporting performance summaries from these systems for this period.

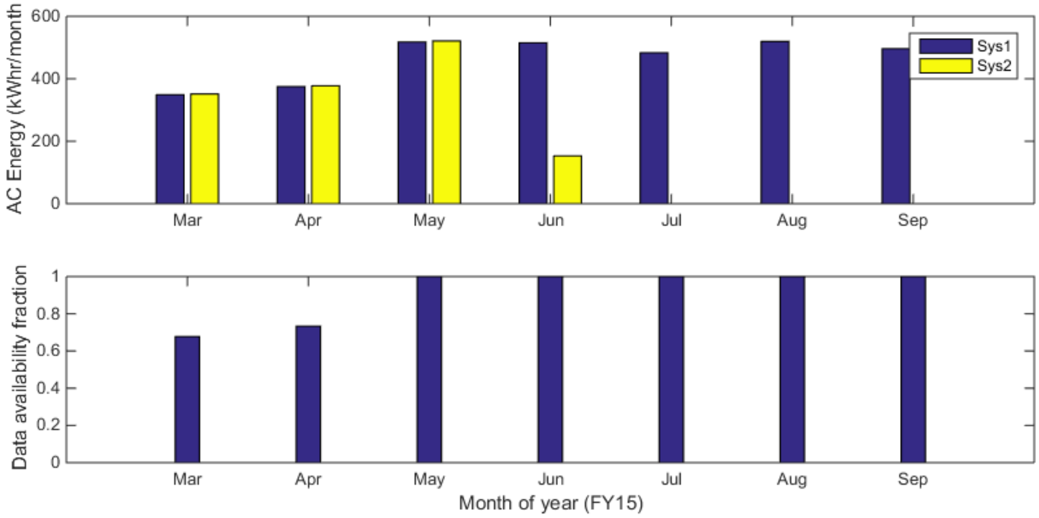

Figure 40. Baseline system AC energy output (top) and data availability (bottom) per month of system operation.

In addition to AC energy from each subsystem, additional data is available from these systems including back of module temperatures, DC string currents, DC system voltage, and plane of array irradiance.

System Performance Comparison Example

One of the purposes of the baseline c-Si system is to use it for comparing the performance of RTC partner systems to this system. In the plot below, we have compared minute-by-minute AC power from the Stion system in NM to the AC power from the baseline system in July 2015. First, the deviation at low power is expected due to site specific shading effects that differ between these two systems, however, shortly after sunrise and before sunset, the irradiance patterns will be nearly identical on these two systems. Second, we have included a best fit line for reference in order to better illustrate any nonlinearity. In fact, the points illustrate a slight concave upwards pattern. This is indicative of the Stion system outperforming, in a relative sense, the baseline system at higher irradiance values. This behavior is likely the result of a lower temperature coefficient for Stion CIGS technology than that of the baseline c-Si cells.

By analyzing these performance differences in detail we can learn a lot about the relative performance of different technologies represented at the RTC in different climate conditions.

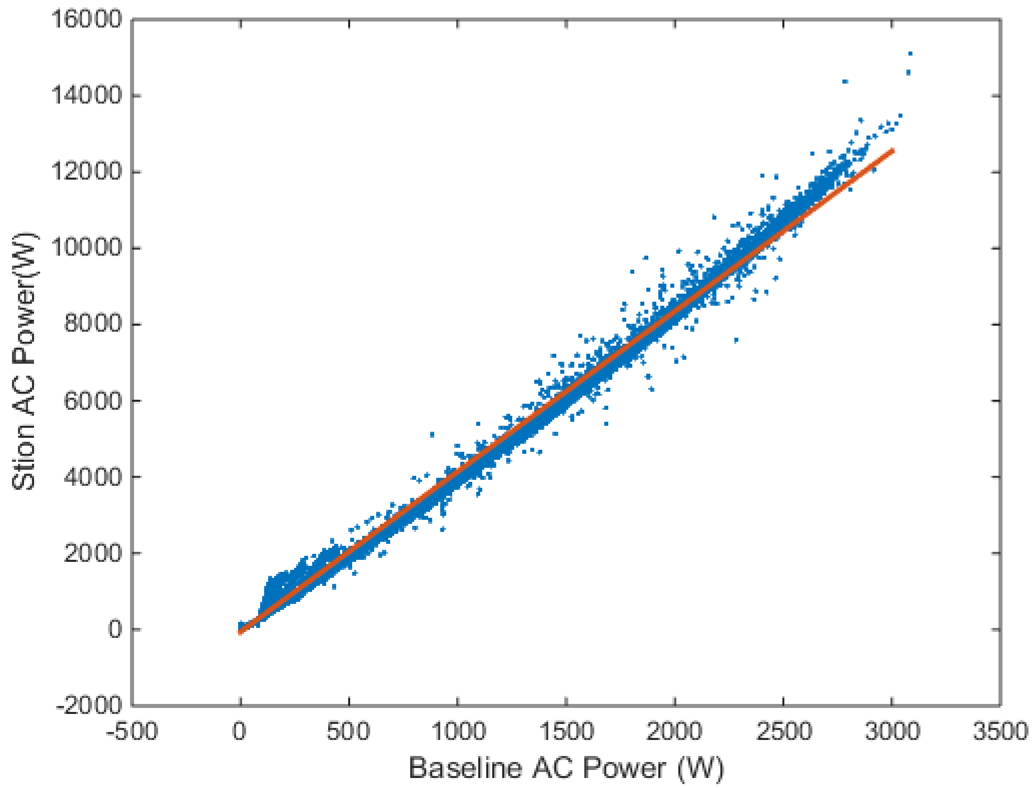

Figure 41. Minute-by-minute comparison of AC power between the Stion and Baseline system in July 2015 at the New Mexico RTC site.

Data Management and Quality Monitoring

The four Sandia managed RTCs, (Florida, New Mexico, Nevada and Vermont) currently have system and weather data flowing into Sandia's Photovoltaic Data Management System (PVDMS). There have been no reported dropouts. Data from this system feeds analysis scripts that are being developed to help automate the performance analysis reports that are delivered to partners.

In FY15 Sandia developed a Database Performance Monitoring Program (DPM) to automatically analyze data collected the day before and check system performance. The DPM software is a python package designed to perform quality control analysis on time series data. The software reads in a time indexed database (currently csv format), performs a series of quality control tests defined by the user, and creates a report which includes summary statistics, tables, and graphics (see example below). The software can be customized to specific applications.

For the Regional Test Centers, DPM is run once a day for each PV and weather system using data collected on the previous day. Each RTC systems is unique in its goals and data requirements. Thus, the quality control analysis for each system is also unique. Summary statistics and graphics are gathered in a dashboard and sent out via email each day. The graphics link to a detailed DPM report for each system.

On a user defined interval, one can use the DPM tool to run summary statistics for longer periods of time (e.g., weekly, monthly, yearly, etc.). For these analyses, we have defined several measures of data quality. The Quality Control Index (*QCI*) is computed for each system. *QCI* is the percent of data points that pass quality control tests. Duplicate and non-monotonic indexes are not counted as failed tests. Duplicates are removed and non-monotonic indexes are reordered. The occurrence of duplicate and non-monotonic indexes are listed in the final report.

QCI is defined as: $QCI = \frac{\sum_{d \in D} \sum_{t \in T} X_{dt}}{|DT|}$

where D is the set of data columns and T is the set of timestamps in the analysis. X_{dt} is a data point for column d time t that passed all quality control test. $|DT|$ is the number of data points in the analysis. A value of 1 indicates that all data passed all tests. For example, if the database consists of 10 columns and 720 times that are used in the analysis, then $|DT|$ = 7200. If 7000 data points pass all quality control tests, then the QCI is 0.972.

For the RTC application, the Performance Ratio (PR) is computed for PV databases and the Clearness Index (CI) is computed for Weather databases.

PR is defined as: $PR = \frac{Y_{fAC}}{Y_r}$

where Y_{fAC} is the AC system yield defined as the measured AC energy produced by the PV system in the day (kWh/d) divided by the rated power of the PV system (kW) . Y_r is the plane-of-array insolation (kWh/m^2) divided by the reference irradiance (1000 W/m^2).

CI is defined as: $CI = \frac{\sum_{t \in T} DNI_t}{\sum_{t \in T} Ea_t}$

where DNI_t is the direct-normal irradiance at time t (kWh/m^2) and Ea_t is the extraterrestrial irradiance at time t (kWh/m^2) modeled using the pvlib for Python.

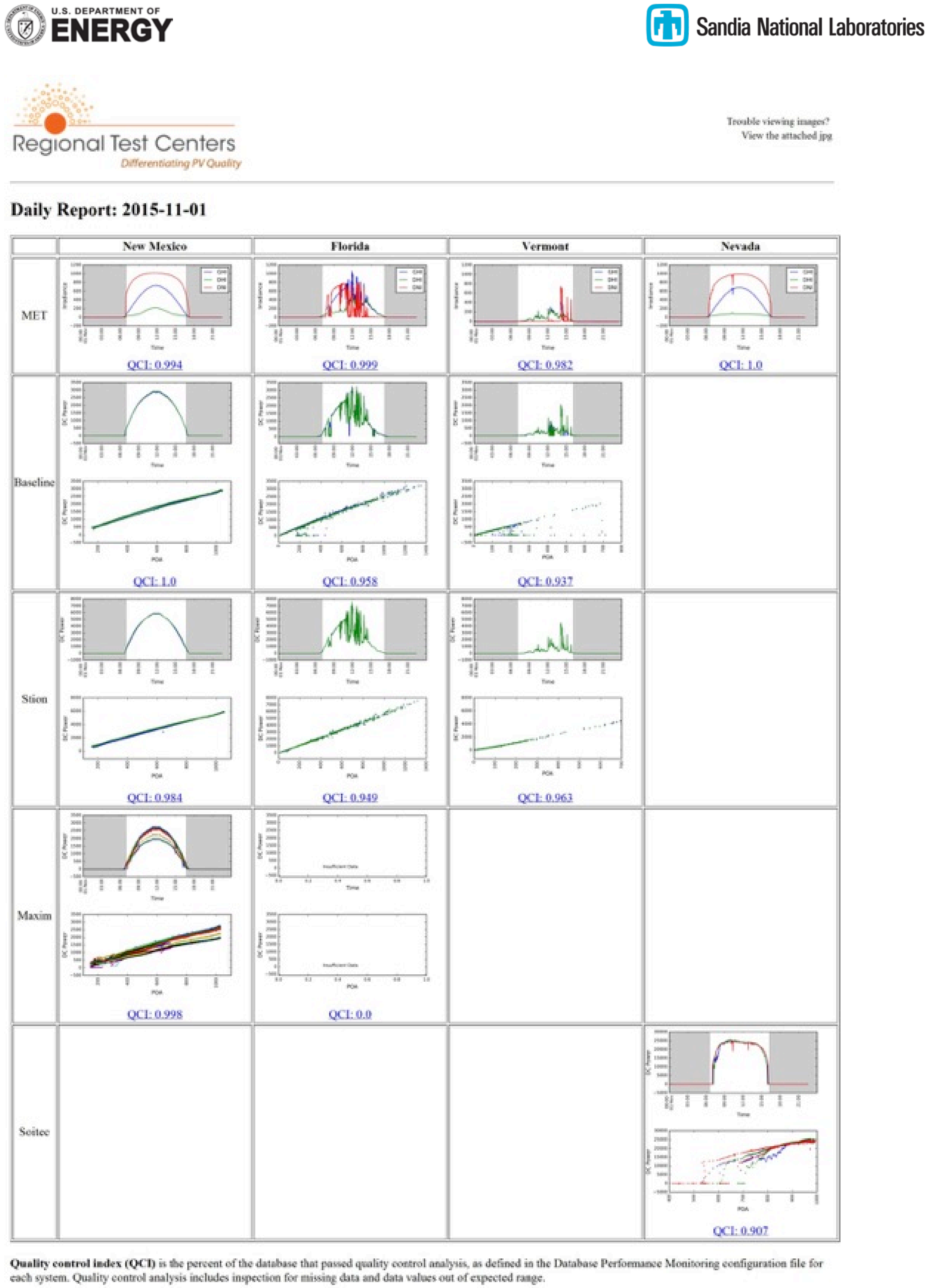

Figure 42. Example of daily email that reports on RTC system health for the previous day.

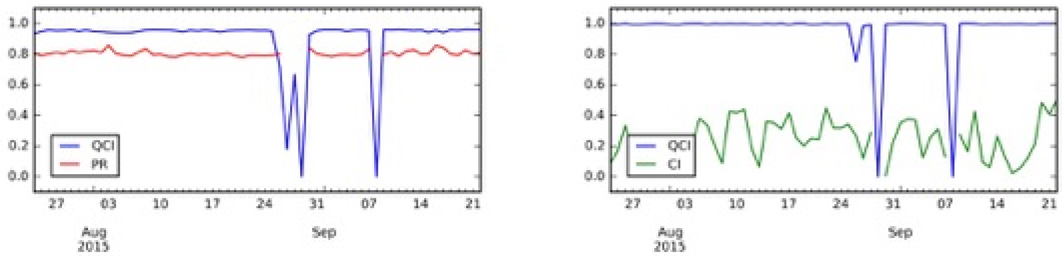

Figure 43. Examples of the quality indices for a PV system (left) and the corresponding weather station (right).

New Business Process

We have a new webpage located at http://rtc.sandia.gov which provides information for potential incoming partners. The new proposal process is more collaborative and efficient at getting new deserving partners into the program. It requires prospective companies to submit a preliminary proposal following guidance on the website. After the proposal is reviewed, there are technical discussions between the company and the RTC team, the RTC team screens and refines the proposal. The RTC and prospective partner adds cost share details, if needed. The RTC team then reviews the final proposal against published criteria and makes acceptance decisions. Once we get to this point, MOU and NDA agreements are finalized and the project commences. DOE guidance has been to proceed with new partner acquisition without obtaining official concurrence from DOE. We have done this as long as we clearly have had sufficient budget resources to perform the work in FY15.

Once a project is accepted into the program, we track its progress through a standard project lifecycle that includes the following steps:

1. **Proposal** – proposal review, feedback and acceptance
2. **Planning** – development of the validation plan and legal agreements (e.g., NDAs, MOUs)
3. **System Design** – preliminary and final design review process
4. **Baseline Testing** – flash testing and calibration of SAPM model on tracker
5. **System Installation** – work with contractors to get system installed
6. **Calibration/Commissioning/Configuration Management** – complete this standard process
7. **System Performance Analysis** – monitor performance of systems daily, monthly and report to partner quarterly
8. **Decommissioning** – implement the decommissioning plan included in the validation plan

Each of these steps requires the completion of a set of predefined deliverables. We are just starting to implement a new software package that will aid us in keeping track of all this information for all the partners and sites.

Outreach

Outreach efforts are ongoing. In FY15, we presented at the SunShot Summit, Solar Power International, and an invited talk at the WCPEC-6 conference in Kyoto, Japan.