PV Variability at the DeSoto Next Generation Solar Energy Center

Cooperative Research and Development Final Report

CRADA Number: CRD-11-425

NREL Technical Contacts: Manajit Sengupta, Aron Habte, and Mike Dooraghi

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5D00-75427
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Cooperative Research and Development Final Report

Report Date: March 14, 2019

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Florida Power & Light

CRADA number: CRD-11-425

CRADA Title: PV Variability at the DeSoto Next Generation Solar Energy Center

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$400,000.00
Year 2	$200,000.00
Modification #5	$20,927.00
Modification #6	$45,000.00
Modification #7	$600,000.00
Modification #8	$2,466.00
TOTALS	$1,268,393.00

Abstract of CRADA Work:

In order to support the continued integration of utility-scale solar photovoltaic sites into the Florida transmission system and to further enhance our understanding of the effects of cloud-induced output variability on the site and transmission operations, participant elects to enter a Cooperative Research and Development Agreement (CRADA) with the National Renewable Energy Lab (NREL).

Under this agreement, NREL will work with participant to instrument their PV plant in DeSoto county FL and obtain solar radiation and power output data. The Florida Power & Light's (FPL) DeSoto Next Generation Energy Center is the largest installed PV plant in the country (25 MW). Our goal is that this site be instrumented and used for research into PV variability and forecasting.

The goals of this project are to:

1. Understand how PV plant output variability is impacted by change in the physical size and production capacity of a power plant
2. Investigate the possibility of using satellite-based information to estimate PV plant production especially larger plants comparable to the satellite footprint
3. Determine the minimum sensor configuration needed to model plant output and its variability
4. Develop a model/algorithm that will describe cloud-induced output variation at PV sites with similar weather conditions.

This work includes, but is not limited to, instrumentation of the DeSoto 25 MW PV plant with fixed radiometers, tracking radiometers, and power sensors; instrumentation of surrounding land (which is proposed for increased PV development) with fixed radiometers; data acquisition, archiving, and retrieval; analysis of data to achieve multiple goals. Work will be conducted at both NREL and Participant facilities.

Summary of Research Results:

Understanding the variability of solar resources is essential for utility scale PV systems. The sudden change in PV energy production due to variability in sky condition is a primary concern. In collaboration with FPL and NextEra Analytics, NREL deployed 17 high resolution solar measurement systems at FPL's 25 MWac DeSoto Next Generation Solar Energy Center near Arcadia, Florida. This deployment provided time-synchronized high resolution solar and power measurements at one second temporal resolution. The goal of this project was to collect high-quality data for multiple years to better understand the relationship between variability in solar energy and power production for Megawatt scale PV deployments. Detailed preparation at NREL's Solar Radiation Research Laboratory (SRRL) was needed to ensure a successful deployment in the field that would provide measurements with satisfied quality. This includes designing and deploying the prototype solar measurement systems around SRRL, calibrating the equipment before deployment, and designing and procuring the communication equipment. It also includes coordination with FPL to ensure that the available utility SCADA network at DeSoto was compatible and capable of integrating the new equipment.

NREL implemented and tested a SCADA based data acquisition system at five stations in late 2011, and at the remaining twelve stations in early 2012, which allows measurement stations to interface the SCADA system and store irradiance and power data on the PI system. However, the communication of the SCADA connection failed after working for a few months. As the reason of the failure could not be determined, NREL retrofitted the stations with new communication at SRRL and shipped to DeSoto for installation. By May of 2014, data collection and communication with the stations was resumed. In addition to irradiance measurements, two ambient temperature, two PV back of panel temperature measurements and two tracker angle sensors were also available.

In August of 2011, the first five solar monitoring stations, including one RSR2 measuring GHI and DHI, were installed outside the fence of the FPL DeSoto PV plant. The configuration of these five stations is shown in Figure 1 (left). In January of 2012, additional eleven LI-Pod stations and one RSR2 were added. The final configuration of stations along with the inside the fence WIMS stations can be found in Figure 1 (right).

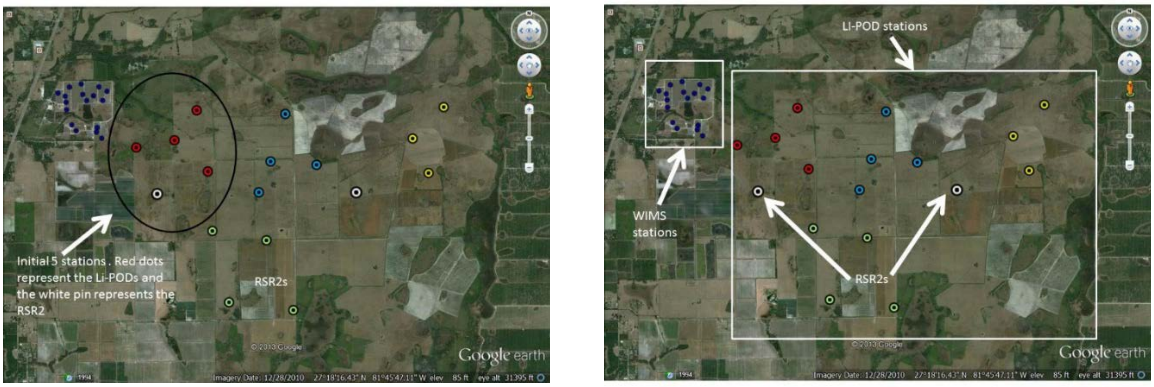

Figure 1. (left) The first 4 outside the fence Li-POD stations and 1 RSR2 and (right) final configuration of all stations inside and outside the fence

Those stations operated until the owner of the land decided to sell his property. As a result, eleven stations had to be removed during November 23 to 25 of 2014 and returned to NREL. In cooperation with FPL, NREL reinstalled three stations on other portions of DeSoto during January of 2015. Figure 2 illustrates the locations of the removed, remaining, and new stations.

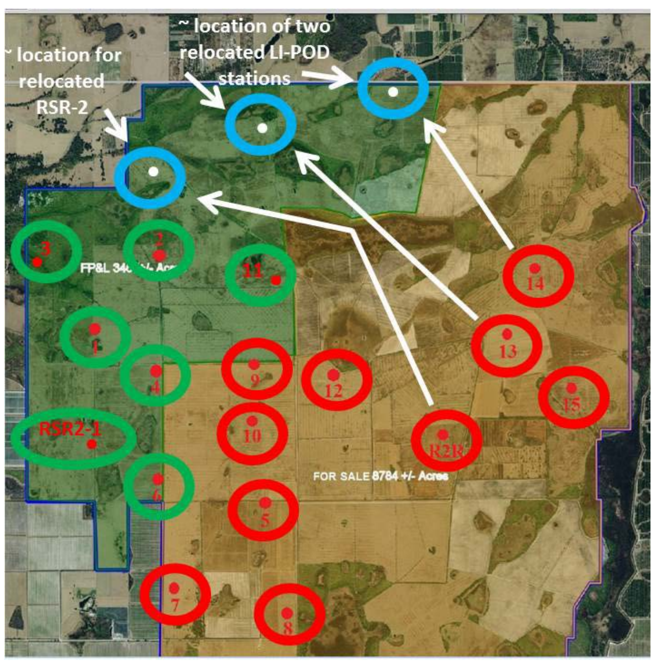

Figure 2. The locations of the 11 removed (red circles), remaining (green circles), and 3 new stations (blue circles).

Besides the sold land leading to removed stations, other challenges existed that affected data quality and quantity. For example, the flood in the summer and fall of 2014 caused difficulties in troubleshooting. Grass around the outside the fence stations and bird excrement also affected the measurements. Due to those challenges, a scheme was developed to screen low quality data from the WIMS and LI-pods stations. The quality-controlled data was used to establish relationships between the POA and power from inside the fence when solar zenith angles are less than 80 degree. The outside the fence POA data can be also determined using measured GHI. A relationship between outside the fence POA and power was developed using the one-second WIMS and LI-pod data for three years.

The DeSoto data has a number of internal and external users. For example, the solar irradiance data from DeSoto PV plant have been extensively used by the University Corporation for Atmospheric Research (UCAR) for validating solar forecast models. The high temporal resolution irradiance data from DeSoto provided modelers a unique opportunity to improve short-term forecasting of solar radiation. Moreover, NREL's Strategic Energy Analysis Center used the DeSoto data to validate Sub-hour Irradiance Algorithm (SIA), which is a supervised learning algorithm from surface observations. It generates high rate (1-minute) synthetic time-series data of solar irradiance using inferential statistics. The DeSoto data was used to validate the SIA since it was not used in the learning process. The DeSoto data was also used by Sandia National Laboratory to validate the National Solar Radiation Data Base (NSRDB) which is a satellite-based long-term high-resolution solar resource dataset developed by NREL.

Task 1: NREL site visit, preparation of detailed plan for instrumentation, data logging, and data quality control.

NREL staff traveled to the site and installed solar monitoring station in the plane of array on the PV plant. The station consisted thermopile pyranometers, photodiode pyranometers and reference cells, along with other metrological sensors and the necessary logging and communication equipment. The details are as follows:

- Wireless Irradiance Measurement Stations (WIMS)
  - 17 spatially dense stations. Data from collocated PV Panels strings, 64 inverters, 17 power containers, and the substation are also available for the period of record (Figure 3).
  - Data is communicated via the RF radio and antenna to another RF radio which interfaced by a cellular modem.
  - Collocated with the PV power production panels.
  - 17 containers each with 2-4 inverters.
  - Each Container has a POA and GHI irradiance measurement associated with its panels.
  - Additional power data was available from the SCADA PI server. Note: Irradiance data prior to May 7, 2014 were collected by the FPL PI Server. After May 7 2014 the stations were retrofitted to be independent of the SCADA communications.

- Additional data included, 2 temperature and relative humidity readings, four back of PV panel temperatures, and an angle measurement on one of the trackers arms.
- Data for one station (pilot station 7) are available beginning August 11, 2011 with the rest coming online around the middle of January.

- LI-PODs – LI-CORs on a tripod
  - 15 spatially less dense stations (Figure 3).
  - 1-second GHI was collected for each of the 15 LI-POD stations.
  - Other data included system battery voltage and logger temperature.
  - Data was available beginning August 10, 2011 for the first four stations. The remaining stations came online around January 10, 2012.
- RSR2 – Rotating Shadowband Radiometer Model 2
  - 2 RSR2s were collocated with the LI-Pod stations (Figure 3).
  - Three second and one-minute GHI, DHI and DNI are measured/calculated at each RSR2 stations.
  - Other available data include temperature, relative humidity, logger voltage and temperature.

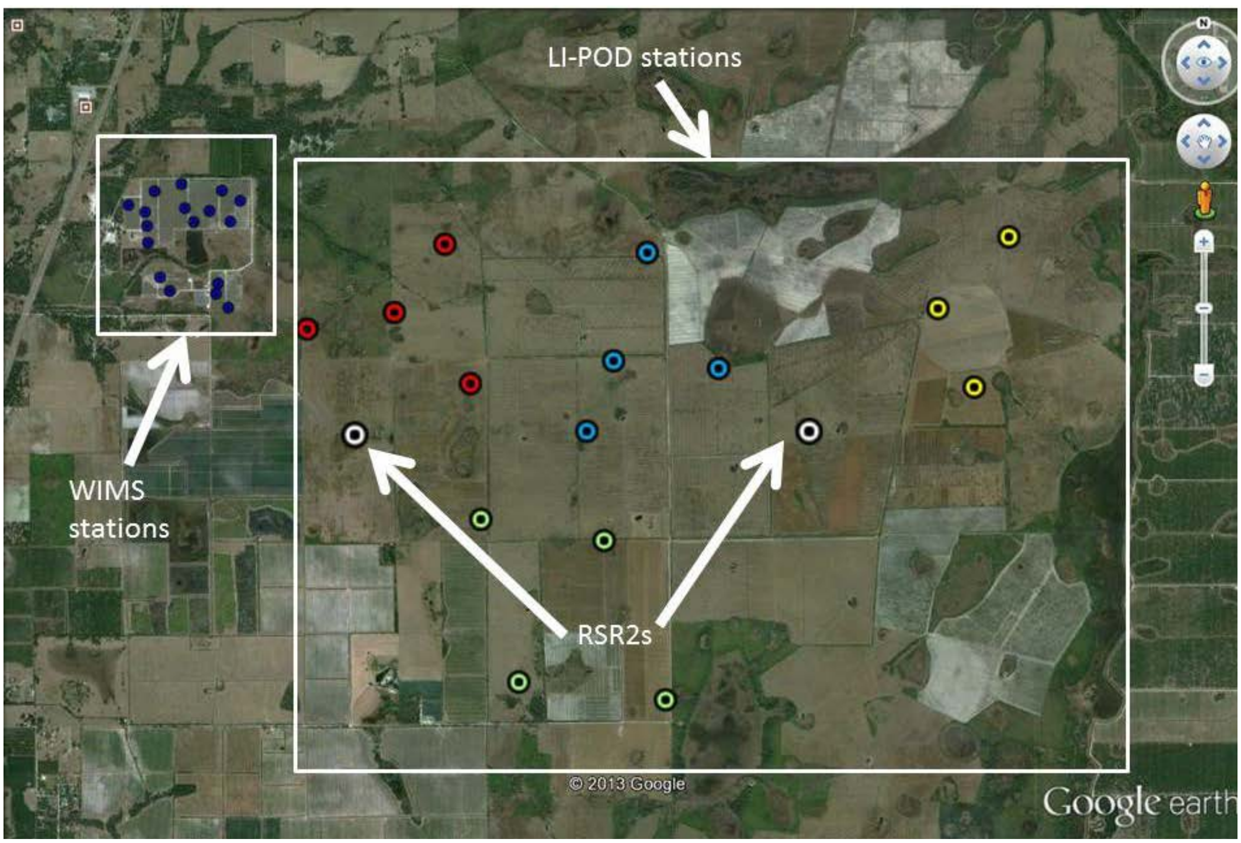

Figure 3. Measurement station distribution and types around DeSoto PV plant

Task 2: DeSoto PV site instrument installation and data acquisition and Task 3: DeSoto expanded area instrument installation and data acquisition.

Originally the solar monitoring stations were connected to Plant SCADA system via Wi-Fi radios (Figure 4). This process worked for a number of months and then communication problems developed with the plant SCADA system resulting in significant loss of data.

Multiple attempts were made by NREL and FPL to resolve this issue, none of which were fully successful. These attempts included

- Reprogramming the settings for the SCADA system
- FPL changed switches in a couple of containers as a test to determine if those were the issues

Antennas were reoriented, reconfigured and replaced. NREL suggested changing the whole communication and logging system such that it would not rely on the FPL SCADA system. Rather the systems would function like the stations outside the PV Plant. The original reasoning for using the FPL SCADA system was to have the data come from one source (the SCADA system) and also, fears of the regular Wi-Fi antennas interfering with the radiation incident on the PV Panels. As it turns out the signal is strong enough that the antennas did not have to be pointed directly and the access point were oriented to minimize the shading affect on the PV production panels.

FPL liked the idea of the retrofit and in May of 2014, 12 stations were retrofitted to operate like the LI-POD stations that are located outside the fence. In early July 2014, the remaining five stations were retrofitted. One station suffered a lightning strike shortly after installation and a replacement was built, tested and sent to Desoto for installation in Mid-August, 2014.

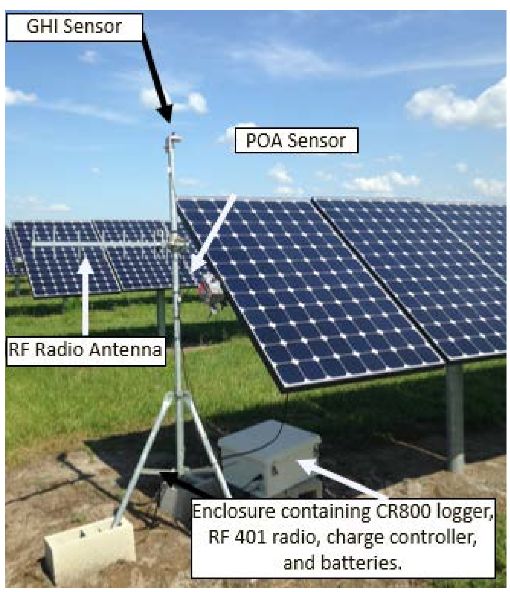

Figure 4. Irradiance Measurement System Collecting POA and GHI data.

Task 4: DeSoto project data analysis and model development.

The data from this project was used to validate the NREL's System Advisor Model (SAM) and a technical report was published[1].

Further, NREL completed an analysis of the quality of the relationship between the three types of solar irradiance measurement devices when compared to measured power (e.g., Figure 5). This information will be used to better understand the relationship between PV production and solar radiation and reduce the uncertainty in PV performance assessment and PV production.

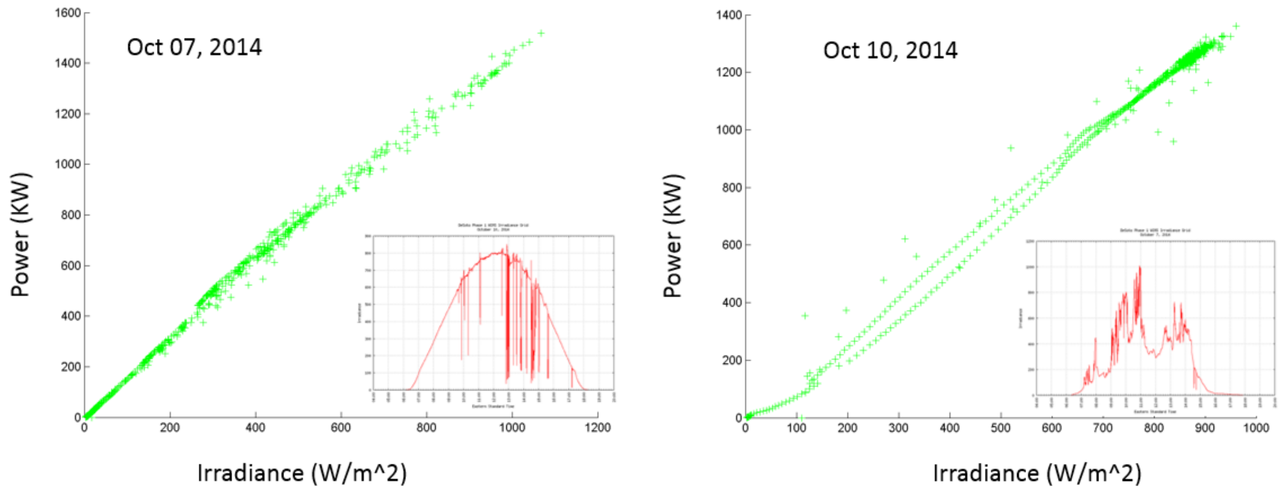

Figure 5. Relationship between one-minute POA and power data for two different days.

Note that on October 10, there appears to be two different relationships throughout the day. On Oct 7, there is one relationship. This is due to a cloudy day on Oct 7, (the effects of tracking being much harder to identify during cloudy conditions) and a clear day on October 10, (during which any issues with tracking are more clearly seen. The bottom right hand of each graph shows the irradiance profile for that day.

Mod 7, Task 1: Install one solar monitoring station in the plane of array inside the fence of the PV plant:

One inside the fence station was installed containing POA LICOR and a GHI LICOR along with POA Kipp and Zonen CMP and GHI CMP and a POA reference cell. The data was distributed through MIDC using a password protected link for internal use.

Mod 7, Task 2: DeSoto project data analysis and model development.

The RSR2 data was processed by NREL's SERI QC using Gompertz curves created from the NREL's QCFIT software.

The quality-controlled data was used to establish relationships between the POA and power from inside the fence when solar zenith angles are less than 80 degree. Linear relationships can be found in Figure 6. It can be seen those relationships are dependent on number of inverters, number or panels, and inverter sizes for the particular container. The configuration of the inverters for each container is shown in Table 1. Note that most containers are 4x420 kW configurations. The averaged ratio of power to POA for the 4x420 kW containers is 1.42 and is

[1] https://www.nrel.gov/docs/fy14osti/60204.pdf

used to simulate power from the inside the fence POA data which is computed by the inside the fence GHI data and a transposition model. Figure 6 and Figure 7 show a good agreement between the simulation of power and the measurements.

The outside the fence POA data can be also determined using measured GHI. A relationship between outside the fence POA and power was developed using the one-second WIMS and LI-pod data for three years.

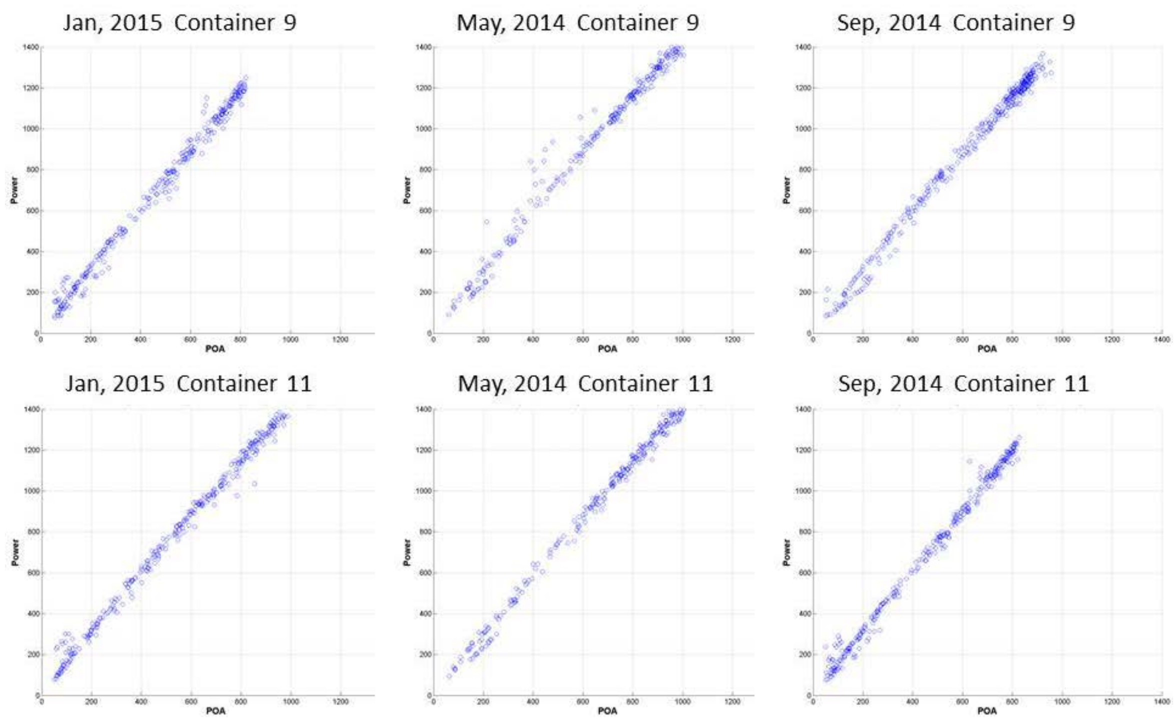

Figure 6. Linear relationships between POA and power based on the measurements from inside the fence.

Table 1: Inverter configurations.

Container	Inverter number	Inverter size (kW)
1	4	350
2, 3, 4, 6, 7, 8, 9, 10, 11, 12 ,13, 14, 15	4	420
5, 16	3	420
17	2	420

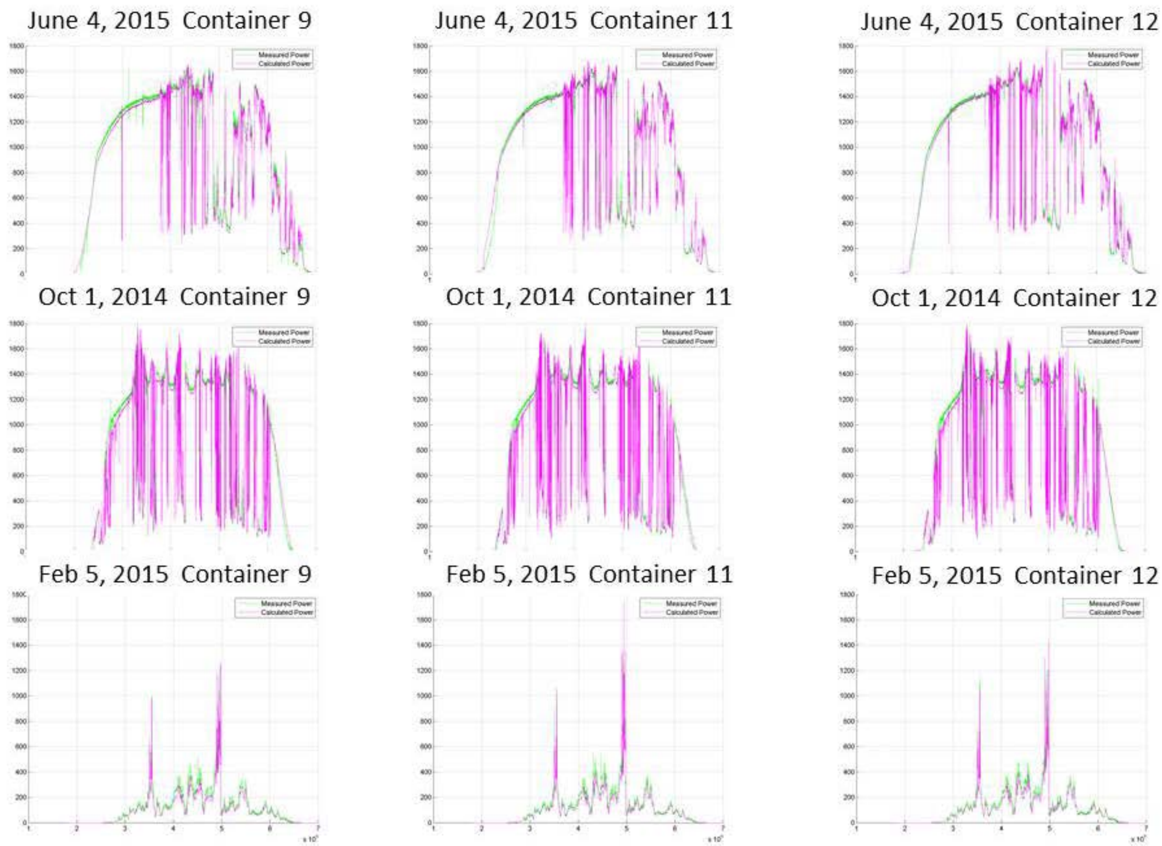

Figure 7. Comparison between measured (purple) and simulated power (green).

Subject Inventions Listing:

None

ROI #:

None

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