FINAL REPORT

Demonstration of Innovative, Cost Effective Micro-cell based Highly Concentrated Photovoltaic (HCPV) System Energy Technology with Optional Storage Capabilities on DoD Installations

ESTCP Project EW-201341

SEPTEMBER 2018

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The technical objective for this project was to deploy commercial-scale HCPV units with a total installed capacity of ~200kWe AC (~220kWe DC) and a short-duration power-leveling battery system. Each of the nine HCPV tracker units were rated at ~24.5kWe DC and this demonstration would have generated data supporting cost, performance, operation and maintenance information needed to make future decisions on HCPV installations.

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ACRONYMS AND ABBREVIATIONS

AR	Aerojet Rocketdyne
COTS	Commercial Off the Shelf
DoD	Department of Defense
DNI	Direct Normal Insolation
EPC	Engineering, Procurement Construction
EAFB	Edwards Air Force Base
HCPV	high concentrated photovoltaic
IEC	International Electrotechnical Commission
IES-UPM	Instituto de Energia Solar at the Universidad Politecnica de Madrid
O&M	operations & maintenance
SCADA	supervisory control and data acquisition
TRR	Test Readiness Review

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1.0 SHORT DESCRIPTIVE TITLE

Demonstration of Innovative, Cost Effective Micro-cell based Highly Concentrated Photovoltaic (HCPV) system Energy Technology with optional storage capabilities on DoD Installations.

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2.0 ESTCP TOPIC AREA

Cost Effective On-Site Distributed Generation

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3.0 LEAD ORGANIZATION

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4.0 SUMMARY STATEMENT

The final report for this project will summarize the accomplishments & status of each task that Aerojet Rocketdyne (AR) had to conduct to complete this project while also describing the situation behind why the demonstration power plant was never installed & completed. All the equipment needed to finish the project has completed fabrication and has been delivered to Edwards Air Force Base (EAFB) where the power plant was to be installed. In the end, an insurmountable amount of site permit requirements and delays associated with the site selection resulted in the project losing momentum and becoming vulnerable to cancellation. On top of this, unfortunately during the duration of this project, Semprius, the HCPV module manufacturer went out of business, thus further cementing the non-viability of the technology going forward after this demonstration project.

It is also unfortunate that the High Concentration Photovoltaics (HCPV) modules and the Lithium Ion batteries could not be demonstrated under operational conditions so that real data could be accumulated. HCPV modules would have needed to become less expensive to be competitive with flat panel PV, but the battery system was the most intriguing component of this project. It would have been a first attempt at energy storage combined with HCPV to level out power levels during intermittent cloud cover or long- r a n g e possibilities of using energy storage to meet energy demand curves at the end of the day during peak usage time.

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5.0 TECHNOLOGY DEMONSTRATION

5.1 TECHNICAL OBJECTIVES:

The technical objective for this project was to deploy commercial-scale HCPV units with a total installed capacity of ~200kWe AC (~220kWe DC) and a short-duration power-leveling battery system. Each of the nine HCPV tracker units were rated at ~24.5kWe DC and this demonstration would have generated data supporting cost, performance, operation and maintenance information needed to make future decisions on HCPV installations.

5.2 TECHNOLOGY DESCRIPTION:

The key HCPV module technology is a μ-transfer printing approach, which allows the use of micro-cells. Micro-cells have a number of advantages over conventional cells, some of which are mentioned below. The approach has the following cost, performance and reliability benefits over existing approaches such as:

- μ-transfer printing which allows the GaAs substrate to be used several times, reducing cell cost
- High concentration of solar flux which reduces cell size and hence cost
- Unique high efficiency two-stage refractive optics implemented with inexpensive material stock which reduces cost
- Short optical path which enables a thin module profile and reduces cost of structural materials
- Distributed zero-cost thermal management which reduces cost by eliminating supplemental heat sink and heat spreader, decreasing module cost
- Low current and low temperature and thin film metal interconnects increases reliability
- Highly scalable and parallel, capital efficient and automated manufacturing process

Figure 1 presents a picture of an HCPV module. The module has a dimension of 636 mm x 476 mm and is 66 mm thick. It has a rated power of 87.5 W and a concentration ratio of 1100 suns. The efficiency of this module was determined to be 33.9% by Instituto de Energia Solar at the Universidad Politecnica de Madrid (IES-UPM).

Figure 1. Current Generation Semprius HCPV Module (636 mm x 476 mm)

The HCPV system was to use modified commercially available dual-axis solar trackers from STi Norland, providing optimum solar alignment with high angular accuracies as tight as 0.1 degrees, allowing for the maximum capture of the solar energy throughout the day. This high accuracy is necessary for HCPV applications in high DNI regions in providing lowest solar electricity production cost. The dual axis tracker also provides > 30% more energy yield than a fixed installation with the same nameplate rating.

For the storage battery, AR chose the equipment provided by Princeton Power Systems. Princeton supplied the batteries along with the battery controller, the inverters, air conditioning unit, fire extinguisher system and the data acquisition computer all inside one equipment container.

5.3 TECHNOLOGY MATURITY:

AR's HCPV system technology was mature; all proof of concept work was completed and was ready for full-scale demonstration. The standard version of these commercially available dual-axis HCPV trackers were demonstrated and verified for its maximum effectiveness. The trackers for this project were modified to suit the needs of the Semprius HCPV modules. The protective logic in the tracker controllers would have enabled a comprehensive communications exchange, allowing the HCPV system to reliably produce electricity at a consistently high level. Robust and optimized tracker structure, using high quality components and materials, would have provided stability throughout the lifetime of the project.

Each tracker was equipped with its own control unit, so each of the nine units could have been individually accessed and analyzed. Only a power supply cable, a grid feed cable and a communications cable would have been needed for operation. The tracker controllers would have been fully integrated with the field-level SCADA (supervisory control and data acquisition) and communications protocol and allowed for bi-directional data exchange from anywhere in the world via internet. This feature would have limited the amount of on-site visits and would have saved both cost & time.

The evaluation function would have allowed for a continuous overview of a customer's investment earnings in real time. Output performance of all crucial data such as irradiance, module temperature, ambient temperature and wind speed would have been displayed. The communications hub allowed for continuous monitoring of the operational data and would have offered a significant time advantage for maintenance and support work.

The HCPV system was equipped with an extensive array of plant protective system features. This would have allowed for reliable operation in extreme conditions, protecting the system even in the events of storms and power failures. A voltage monitoring system would have continuously checked the charge level of the control batteries so that the secure stow position could have always be accessed when needed. A wind speed indicator includes a wind sensor and control unit. This ensures that each HCPV unit automatically would have moved into a secure stow position in case of high winds. The energy storage system used readily available commercial products with standard issue Lithium-Ion batteries.

The demonstration would have provided standalone electrical power service to a single point electrical power connection. Data would have been gathered and processed locally within the demonstration plant and transmitted by a commercial wireless internet connection for analysis.

5.4 SUMMARY OF TASKS

AR led the team of sub-contractors in the following activities:

Task 1 – Site Selection: During the course of this project, AR selected two different sites and the entire process took 26 months to obtain the necessary site permit at Edwards AFB. AR anticipated the site permitting to only take a couple of months, so this length of time led to a loss of momentum for the project. The permit requirements from EAFB were much more extensive than originally anticipated and while AR did our best to mitigate these delays it still required an excessive amount of time to obtain the required permitting. Figure 2 shows a concept of the 9 tracker arrangement.

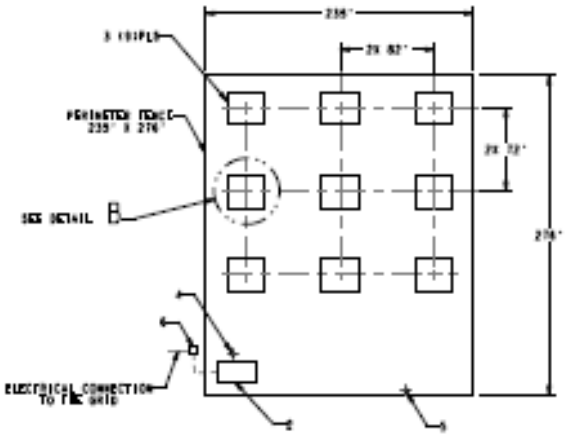

Figure 2. HCPV Deployment Concept at AFRL

Task 2 – Demonstration Plan: A draft version of the demonstration plan was submitted to the ESTCP office in 2015. The plan explained the data characteristics that were important to monitor performance and health monitoring hardware & software to meet data transmission capability and storage capacity.

Task 3 – Project Site Design: The 60% preliminary site design was completed in late 2017. This included the geological technical investigation of the soil at the site, the overall site electrical design and the structural concrete designs for the tracker & electrical equipment pads. A preliminary glint/glare report was also completed that stated there would have been no issue posed to flight operations at the base from the HCPV trackers. An important item was making sure that the hardware and software met grid standards for accumulation of the electric power produced by the trackers in the HCPV field and for converting that source power into grid compliant electrical energy product at the EAFB site interconnect. Figure 2 shows the intended site layout of the tracker equipment.

Task 4 – Project Hardware: The 2,520 HCPV modules, solar tracker equipment for nine trackers, electrical equipment container with battery system (~10 minutes of battery coverage (250 kW/127 kWh)) & electrical inverters (two full capacity inverters were procured, one as a backup) are completed and have been delivered to Edwards AFB. This represents all the major hardware that was needed for the project.

Task 5 – Construction Specification: A construction specification that defined the scope of activities at the project site and construction standards to be invoked for workmanship, inspection and project buy-off was created and was the document used to receive quotes from the Engineering, Procurement & Construction (EPC) service companies.

Task 6 – EPC Engagement: A contract with The Ryan Company, an EPC firm, was initiated to complete the engineering design of the overall plant and construction details. If construction of the project would have happened than AR would have continued with this EPC company as their performance was good. The EPC would have laid the concrete pads, installed the trackers, connected all the HCPV panels to the inverters & batteries and then connected the entire plant to the high voltage power lines that feed the base electrical system.

Task 7 – Site Permitting and Preparation: This is one area where the project suffered from the delays in the process of obtaining the site permits. The 26 months it took to satisfy the permit process was easily 10 times longer than what was understood as the process. The details were far more extensive than initially presented and a required site change added an additional 6 months to the process. This is one area of the project that severely negatively impacted the momentum of the project and which needs to improve if future energy projects at EAFB are to be successful.

Task 8 – Hardware Procurement: All hardware for this project was procured with the normal AR systems and personnel. All hardware on purchase orders has now been received and delivered. No open actions remain.

Task 9 – Installation Monitoring and Oversight: This was a task that AR did not start as construction never was initiated.

Task 10 – Finalize Operations Planning: This was a task that AR did not finish as construction of the plant never started.

Task 11 – Test Readiness Review (TRR): This was a task that AR did not conduct.

Task 12 – HCPV Field Characterization: Characterization of the installed equipment cannot happen due to the plant not being installed. Characterization would have included, but was not limited to: 1) Measuring and documenting non-linear power output variations for the HCPV module and the integrated HCPV unit by 'masking' predictable shadowing patterns that would be expected during typical weather patterns; 2) System performance characterization during the various modes of operation: start-up, forced shutdowns, cloud transients, and normal operation; 3) Tracking and documentation of detailed non- recurring and recurring cost elements to establish cost basis and opportunities for cost reductions for future installation of varying rated capacity and overall production volume; 4) Characterization of HCPV plant operations and maintenance to establish availability and cost requirements due to hardware adjustment or replacement, module cleaning, etc.

The intent would have been to establish a basis for overall cost of ownership, and to detect opportunities to improve maximum annual power output (kWh/kWp); and 5) Integrating the interacting cost, performance and O&M characteristics into already- existing solar field optimization tools enabling robust optimization of annual field performance and capital cost by optimizing field layout over flat or uneven terrain for various DoD locations.

Task 13 – Extended Monitoring: This task was not started as the power plant was not installed.

5.5 TECHNICAL RISKS WITH OUTCOMES:

New technology risk: *Outcome* – Semprius modules were subjected to a battery of IEC 62108 reliability tests with no reported issues. All 2,520 CPV modules were fabricated with advertised module efficiencies.

- Availability risk of battery: *Outcome* –The original battery company did go bankrupt before the project started, but during the initial stages of the project three different companies were found that could offer the battery and so normal procurement strategies of finding the lowest cost bidder were able to be maintained. Princeton Power Systems ultimately won the contract, finished fabrication and delivered their hardware successfully.
- Systems integration risk: *Outcome* – AR did not encounter issues with systems integration as our company was well experienced at working as systems integrator.
- Site coordination risk: *Outcome* – AR was well positioned to mitigate this risk with AR employees already stationed at EAFB and the close proximity of the LA facility to EAFB, however in the end this risk never materialized as installation of the equipment did not happen.
- Project execution risk: *Outcome* – AR successfully managed project execution by continually keeping the project moving forward through all the delays that were not the fault of AR.
- System validation risk: *Outcome* – The plant was not installed, therefore no data was able to be gathered on system validation.

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6.0 EXPECTED DOD BENEFIT NOT REALIZED

Unfortunately, the opportunity to measure and develop experience with HCPV technology did not materialize with this project. This is a lost chance to gain valuable operational data on HCPV modules, trackers, batteries and the battery management controller that were developed for this project. The battery in particular could have provided information on renewable energy storage potential and effectiveness. The relatively short duration energy storage battery system could have improved the stability of micro- grids by utilizing COTS energy storage modular solutions. The demonstration could have provided a pathway to show the potential for larger battery systems where the availability of energy, independent of the sun, would have enhanced grid and base security.

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7.0 SCHEDULE ISSUES

The schedule issues on this project concerning the delays at obtaining the site permits, but also the financial difficulties of Semprius were obstacles that the project could not overcome.

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    - “High Concentrated Photovoltaic (HCPV) Deployment by Aerojet Rocketdyne”

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