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Concentrating Photovoltaics: Collaborative Opportunities within DOE's CSP and PV Programs

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Concentrating Photovoltaics: Collaborative Opportunities within DOE's CSP and PV Programs

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ABSTRACT

The Department of Energy's (DOE) Concentrating Solar Power (CSP) Program is investigating the viability of concentrating photovoltaic (CPV) converters as an alternative to thermal conversion devices such as Stirling or Brayton cycle engines that have historically been supported by the program. Near-term objectives for CPV-related activities within the program include development of in-house analytical tools and experimental facilities in support of proof-of-concept demonstrations of high-concentration CPV components and systems. SolTrace, a Monte Carlo-based optical simulation tool developed at the National Renewable Energy Laboratory (NREL), has been used extensively to analyze primary, secondary and receiver optics associated with in-house and industrial CPV configurations. NREL's High-Flux Solar Furnace (HFSF) has been adapted and used for preliminary testing of dense-packed arrays. Several research and development subcontracts have been awarded for the development and fabrication of components and systems. Hardware resulting from these subcontracts has been delivered to NREL and is undergoing evaluation at a CSP test facility located on South Table Mountain, Golden, Colorado.

INTRODUCTION

DOE funding of concentrating parabolic dish systems dates back to the earlier 1980s. To date, efforts have focused on the development of dish/Stirling systems because of the Stirling cycle's potential for very high thermal-to-electric efficiencies - greater than 40% for engines operating at temperatures higher than 700^{o}C. Peak net solar-electric efficiencies, which include concentrator, receiver, and parasitic power losses, have been measured as high as 30% for these systems [1].

Although developmental dish/Stirling systems have demonstrated very high overall conversion efficiencies, they continue to be hampered by problems of reliability (e.g., leakage of working gas through dynamic and static seals or control-systems hardware failures). The manufacturing costs associated with building a limited number of engines to the level of engineering tolerance required by Stirling engines has also prevented significant penetration into non-solar applications such as prime movers for automobiles or stand-alone generator sets for distributed applications. Significant penetration into such markets is essential to lowering the ultimate cost of Stirling engines [2]. Although some dish/Stirling systems have demonstrated sufficient performance to warrant continued DOE support aimed at improving reliability and lowering costs, the CSP program has recently looked toward alternative converter technologies for use with concentrating dish systems.

Concentrating photovoltaic receivers are an obvious candidate due to their potential for high reliability, high efficiency, and low cost at moderate production levels. In addition, manufacturers within the photovoltaic and concentrator communities seem eager and willing to participate in developmental and commercialization efforts. A recent review by Swanson [3] clearly described the potential advantages (e.g., lower cost, higher efficiency, materials availability, manufacturing scale-up) of concentrating photovoltaic systems over flat-plate systems, especially for large installations. A subsequent study provided data demonstrating a 37% increase in the annual output of a tracking concentrating system versus a non-tracking flat-plate system oriented south and tilted at latitude [4]. The improved performance was demonstrated in Sunnyvale, California, a non-optimal area for tracking solar collectors due to the presence of cloudy weather associated with northern California's coastal regions. Such data not only establish the technical viability of photovoltaic receivers as an attractive option for dish concentrators, but also establish credible evidence that CPV systems may be an alternative to large flat-plate PV installations if the reliability of tracking systems can be demonstrated.

CSP ACTIVITIES

The CSP program's general expertise in the analysis and testing of concentrating systems and associated components offers an excellent opportunity to apply existing analysis tools and facilities in support of CPV development. Several issues are commonly raised when discussing the technical viability of CPV systems. Such issues include optical design requirements for delivering uniform flux to a dense-packed PV array plane, construction of the dense-packed array itself, the added cost and complexity associated with 2-axis tracking hardware and controls, cooling of the photovoltaic array to minimize output losses resulting from increased cell temperatures and integration of each of these components into a reliable operating system. Many of these issues are currently being addressed by the CSP program through a combination of in-house and subcontracted R&D efforts.

Flux Uniformity

SolTrace, an NREL-developed Monte Carlo simulation tool, has been applied extensively to analyze CPV configurations. Space does not permit a detailed description of the analysis; however, results indicate that it is possible to achieve acceptable levels of flux uniformity with minimal receiver intercept losses, for both existing dish designs and when primary optics are configured for uniform (CPV application) rather than peak (thermal application) flux profiles.

CPV Converter Development

The CSP program has established subcontracts with three CPV-related companies to develop a range of converter configurations representing current, near-term, and future configuration options. Amonix is developing an improved dense-packed module using its high-efficiency silicon solar cells. Spectrolab's multijunction cells have the potential to significantly improve module efficiency. Finally, United Innovations' unique cavity concept is a higher risk, higher payoff approach. With sufficient programmatic funding, it should be possible to continue testing of prototypes and develop these to the point of integration into commercial systems.

Tracking and Controls

Tracking hardware necessary for operation of concentrating systems must be proven reliable if such systems are to compete effectively with flat-plate devices. Two 2-axis tracking drives, developed under subcontract to NREL, have been delivered to NREL's South Table Mountain site for long-term reliability and performance tests. A video-based system has been designed to monitor the tracking accuracy of these and future systems.

System Integration

NREL is supporting Concentrating Technologies, Inc. (CTek) with the development of an integrated CPV-based system. CTek has delivered and installed a primary concentrator and associated controls (Figure 1) at the South Table Mountain location.

Figure 1: CTek's primary concentrator consists of more than 500 flat mirrors directed toward a secondary flux homogenizer. The system will be tested at NREL's South Table Mountain site.

A receiver consisting of secondary flux-smoothing optics, a dense-packed array based on SpectroLab's III-V triple-junction terrestrial cell, and active cooling hardware will be delivered before the end of the year. The first-generation system has not been completely optimized, but should provide a proof-of-concept demonstration of a high-concentration (>300 suns) system. This will provide an excellent opportunity for collecting and analyzing extended operational and performance data on a fully functional CPV system.

AN OPPORTUNITY FOR COLLABORATION

The development of CPV systems offers a unique opportunity for collaboration between DOE's CSP and PV programs. Table 1 describes a potential division of activities along lines of expertise between the two programs. Near-term activities describe activities already under way within both programs. Mid-term activities describe high-priority efforts that will require funding over the next several years. Long-term activities describe the overall objective of achieving program goals of 33% for net solar-to-electric conversion efficiency.

	PV Program	CSP Program	CSP-PV Collaboration
Near-Term **1-3 years**	– Multijunction cell R&D – Broad LOI for PV concentrator concepts (HiPerf - phase 1) – Measurements & characterization	– Flux uniformity – Dense-array designs – Tracking and controls	– Technical coordination – PV and CSP LOI/RFP proposal reviews – On-sun testing (stand-alone systems, spectrum, on-sun testing at HFSF)
Mid-Term **2-7 years**	– Demonstrate 34% cell under concentration – LOI for PV concentrator concepts (HiPerf – phase 2)	– Small-scale proof-of-concept – Thermal management – Flux uniformity – Scale-up issues (10-25 kW systems)	– Technical and programmatic coordination – Receiver integration issues – Durability/lifetime testing concepts – CPV balance of system – CPV standards (spectrum, test methods, certification)
Long-Term **8-11 years**	– 40% multijunction cell – pre-commercial 33% concentrator module efficiency	– Optimized large-scale concentrator and controls	– High-efficiency large-scale systems

Table 1: Current activities and potential collaborations between CSP and PV programs fall along current lines of expertise.

Substantial progress has been made in coordinating CPV activities within the CSP and PV programs. Achieving DOE's efficiency goal of "one-third of a sun" will require overcoming additional hurdles – both technical and programmatic. However, this challenge is within reach given the combined expertise that exists within DOE's solar programs.

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