Hybrid CSP/PV receivers: converting optical spillage to electricity

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1. Introduction

Optical spillage from heliostats and parabolic trough collectors occurs due to surface aberrations, misalignment, and tracking errors in concentrating solar power (CSP) plants. In central receivers, spillage is accommodated using heat shields fabricated from high-temperature refractory materials above and below the receiver tubes to protect headers and other infrastructure components. In parabolic trough systems, metal bellows shields (collars) spaced several meters apart are used to protect the expansion joints connecting the receiver tubes from concentrated sunlight. This paper introduces a novel receiver design concept that implements photovoltaic (PV) cells on these heat shields and bellows shields to generate electricity from concentrated light that would otherwise be wasted (Figure 1). A combination of conventional silicon and multi-junction concentrating PV (CPV) cells were evaluated to accommodate regions of both high and low solar fluxes. Estimates from PHLUX imaging [1] show that the irradiance on central-receiver heat shields can be well over 100 kW/m^2 near the receiver tubes, but lower fluxes can occur in distant regions or in parabolic trough applications. A technoeconomic study was performed to estimate the levelized cost of energy (LCOE) for these systems as a function of several cost and performance factors, such as irradiance, PV cell type, and cooling requirements.

Figure 1. Conceptual design of PV cells on heat shields or standby regions of a central receiver (left) or on the bellows shields of a trough receiver (right).

2. Approach

The PV cell temperature, power generation, and LCOE for different hybrid receiver configurations were evaluated using the following procedure:

1. Develop steady-state heat transfer model using a control volume of the PV cells with consideration of solar irradiance, radiation to the environment, convection to the environment, and energy conversion to electricity (which depends on the PV cell efficiency as a function of temperature and irradiance)
2. Determine the cell temperature that satisfies the steady-state energy balance as a function of irradiance (implicit equation)
3. Determine potential power generation for different receiver configurations and available area[1]

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[1] At the Ivanpah Solar Electric Generating System (Figure 1), over 1000 m^2 of area is estimated to be available to accommodate PV cells on the heat shields for each of the ~100 MW$_e$ tower units. For a 50 MW$_e$, parabolic trough plant, nearly 700 m^2 are estimated to be available on the bellows shields to accommodate PV cells.

4. Evaluate costs of components and determine LCOE for PV generation from different hybrid receiver configurations

Analytical heat transfer models were derived to estimate the cell temperature as a function of irradiance and heat transfer coefficients for the application of PV cells on flat heat shields. More detailed computational fluid dynamics models were used to estimate the cooling and heat transfer coefficients associated with finned PV-lined collars that could be used in place of the bellows shields for parabolic trough receivers. Cost and efficiency curves were obtained from literature and from data for silicon and triple-junction PV cells and other components such as heat exchangers. Our investigation of CPV cells in hybrid system applications considered both established triple-junction CPV cells, such as the SolAero Concentrating Triple-Junction (CTJ) cell, and next-generation CPV cells that are being developed for high-temperature applications (e.g., up to 400°C per the ARPA-E FOCUS project; https://arpa-e.energy.gov/?q=arpa-e-programs/focus).

3. Results

Figure 2 shows an example of the estimated LCOE of the CPV generation as a function of irradiance and cooling mechanisms for SolAero CTJ cells applied to heat shields of a central receiver CSP plant. Results show that with passive cooling, a clear minimum exists at ~60 – 80 suns, but the LCOE is quite high at ~\$0.20/kWh. With active cooling, the LCOE drops to less than \$0.10/kWh as the benefits of lower temperatures and higher cell efficiencies outweighs the additional costs of the cooling system (the active cooling system could also be used to preheat the heat-transfer media, which was not considered in this study). Similar analyses were performed with conventional silicon PV cells, and results show that minimum LCOE values were achieved at relatively lower irradiances due to lower cell efficiencies. It is proposed that silicon PV cells be used in regions of lower irradiance (~10 – 50 kW/m^2), and multi-junction cells with active cooling be used in higher irradiance regions to yield the lowest LCOE values for hybrid CSP/PV receiver configurations. Detailed results of both the hybrid CSP/PV receiver configurations for power towers and troughs will be presented in the full paper.

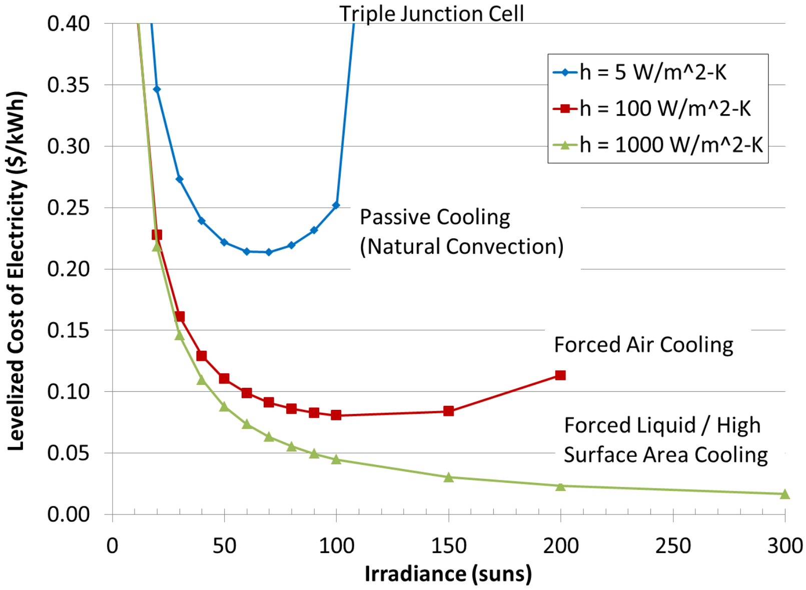

Figure 2. Levelized cost of energy as a function of irradiance and cooling mechanisms for triple-junction cells applied to heat shields of a central receiver CSP plant.

References

[1] Ho, C.K. and S.S. Khalsa, 2012, A Photographic Flux Mapping Method for Concentrating Solar Collectors and Receivers, *Journal of Solar Energy Engineering-Transactions of the ASME*, **134**(4).