2020

Task 1: Improving PV Module Efficiency Through Cooling

Proposed by National Renewable Energy Laboratory
Sponsored by The El Paso Electric Company

Background

The primary area of research in solar energy technology today is increasing the efficiency of photovoltaic (PV) cells and modules. Since most PVs lose efficiency as temperature increases, much current research focusses on reducing the operating temperature of PV cells. Efforts to decrease the temperature of photovoltaics have the added benefit of prolonging the life of a PV module because elevated temperatures activate degradation mechanisms within a module. We consider a “PV module” to be a set of multiple PV cells that are interconnected and packaged for outdoor use.

In full sun, the temperature of a typical PV module may rise as much as 25°C above the ambient temperature because some of the incident light is converted to heat. Though there are expensive high-performance exceptions, for the average PV module, performance decreases on the order of 0.3% - 0.5% per degree Celsius increase experienced by the cells. This results in a loss in power of approximately 10% for every 20°C to 30°C rise in temperature. The conclusion is that even modest reductions in operating temperatures can significantly improve the power output of a PV cell.

PV cells currently operate on the order of 20-25% efficiency, depending on the cell. In general, the higher the efficiency, the costlier the cell. Conventional C-Si (Crystalline-Silicon) solar cells have a theoretical maximum efficiency of around 29 per cent, as there is a limit to how much sunlight can be converted into useful electricity within a silicon PV cell. This efficiency limit is known as the Shockley-Queisser limit.

Active cooling approaches, such as pumping coolant through pipes that pass across the modules or spraying with liquid have been considered. Though these techniques have been demonstrated to cool the modules, their initial costs, monitoring, maintenance, potential to introduce new failure modes, and/or their area footprint have proven prohibitive for scaling to large-scale PV arrays.

There are passive cooling strategies that show some promise, including

- Desiccants
- Phase-changing materials
- Optical coatings (require specialty equipment and technical expertise)

Other cooling strategies are possible, and for any cooling methods, the engineer must consider the trade-offs for solutions that displace panels in a solar array by taking up valuable real estate or that increase costs incurred by additional equipment, monitoring, maintenance, introduction of new failure modes, and/or introduction of energy drains on the system.

Task 1: PV Module Efficiency Through Cooling

Problem statement

Your team will research, evaluate, and design an efficient and sustainable means for improving energy yield of PV modules by reducing the operating temperature of the modules. The solution should allow for energy-efficient, logistically reasonable, and cost-effective scale-up to large PV arrays.

The solution should be an innovative approach to the challenge that does not duplicate previously published designs.

Preliminary Design Submission

The Preliminary Design is due as early as possible, but no later than January 27, 2020.
The Preliminary Design is a brief design report, including design layout and a thermodynamic study that assesses the predicted efficiency of the planned design.
Purpose: Our staff will review your design to ensure that it is technically and thermodynamically sound to ensure that each team is working on a competitive design.

Design Considerations

Your proposed design should provide specific details and outcomes as follows:

- Design a PV-module cooling method that achieves significant temperature reduction and improves energy output of a solar module.
- The cooling method must not damage nor alter the photovoltaics, the intended functionality of the PV module, nor lead to conditions that will introduce degradation mechanisms.
- The cooling method should consider scale-up and minimize the footprint of components that are external to the PV module (if any).
- The cooling method should be self-contained and self-sustaining, requiring little replenishment, monitoring, or maintenance for many years.
- Any off-module equipment, if connected to the module, must be made of materials will remain flexible for many years to allow for daily single- or double-axis tracking.
- The design must be durable under normal weather conditions (sun, wind, rain, and occasional moderate freezing temperatures).
- The materials must comply with current environmental regulations.
- Operating costs should result in improvements over the Levelized Cost of Energy (LCOE) for current technology (LCOE as published by DOE reports).
- The design must allow for effective and efficient scale up to an industry-scale array.

For all solutions, the team must consider these factors:

- Solutions that occupy additional land space may displace primary PV panels, reducing the potential for an entire array to produce power, thus reducing LCOE.
- Solutions that require frequent monitoring or maintenance may increase operating costs.
- Solutions that cool the panel remotely may place unacceptable energy drains on the system, even if they increase the energy efficiency of one panel.
- Teams are cautioned that piped cooling methods and water-spraying methods have not, to date, proven viable, due to scale-up issues and introduction of failure modes.

Bench-Scale Demonstration

The bench-scale demonstration serves to illustrate the design considerations listed above.

Each team will bring to the contest:

1. **A minimum of one PV panel** that is ready for testing.
   Watch the FAQs–WERC may be able to provide one panel for each team. If we are unable to provide this panel, the WERC staff will request that each team purchase a specific panel and will indicate the brand and specifications for the panel.

   To allow for module-to-module variability, provisions for measuring power ratings under standard testing conditions (STC) for each module will be made. (Watch the FAQs online for more information).

   Teams may wish to procure additional panels for preliminary testing. Obtaining additional panels will be the sole responsibility of each team.

2. **A rack** for the panel that allows for variable angle adjustments.
   Watch the FAQs–WERC may be able to provide a rack for all panels during testing in Las Cruces.

3. **Any auxiliary equipment needed for the demonstration.** Treatments to the module should be prepared prior to arriving at the contest.

During the bench-scale demonstration, all teams will set up their system in a common shady/indoor location and move the modules and other equipment into full sun at the same time. Modules will remain in the sun for a minimum of a 1-hour warm-up period prior to testing. This time may be extended.

During the test, the team's PV module will be connected to a calibrated and controlled load as well as a data logger to regularly monitor the temperature, current, and voltage of each team's module during the test.

Analytical Testing for the Bench-scale demonstration:

1. All PV modules will be stored overnight in the Farm and Ranch museum at ambient indoor temperature.
2. All PV modules will be set up in the shade/indoors and moved to full sun at the same time.
3. The angle and orientation of the panels will be specified during bench-scale setup. (Latitude tilt 32^{o})
4. A one-hour (minimum) warm-up period will precede data collection to allow modules to reach equilibrium.
5. The test will run over a period of 4 hours (10 AM – 3 PM) minimum; the time may be extended.
6. The data collected regularly from each module will include the current and voltage output and the module temperature.
7. Additional data collected from the rack will include ambient temperature, control module temperature, solar irradiance, wind speed, and wind direction.
8. To evaluate the relative efficiency of each design:
   a. An I-V Curve will be plotted by connecting an I-V Tracer to each team's module.
   b. Energy, in terms of watt-hours (Wh), will be computed at the end of the testing period.
9. WERC will use an untreated PV module as a control to evaluate the temperature reduction and any improvement in energy output for each team's PV module.

In addition to the bench-scale demonstration, teams may include video productions, computer simulations, tabletop displays, and scale or architectural models to assist in the presentation; these inclusions can be extremely beneficial to your presentation, but shall not be substitutes for the bench-scale demonstration.

Written Report Requirements

The written report should demonstrate your team's insight into the full scope of the issue and include all aspects of the task and your proposed solution. The report will be evaluated for quality of writing, organization, clarity, logic, and coherence. Standards for publications in technical journals (e.g., APA, CBE) apply. In addition to the listed requirements, your report must address in detail the items highlighted in the Problem Statement, Design Considerations, and Evaluation Criteria sections.

Particular to this task, your report should:

- Include a thermodynamic study of the design.
- Address scale-up of your design to a 100 MW array
- Present a detailed cost/efficiency study that addresses overall system efficiency of a scaled-up design. Your LCOE should consider additional real estate required (if any), start-up costs, monitoring, maintenance, degradation/replacement, and energy efficiency of the entire system. If additional loads are added, this must be addressed.
- Address the design's compliance with current environmental regulations.
- Indicate the innovative aspects of the design and discuss improvements over previous technologies. Solutions that are variations on previously published designs require a stringent literature review and a discussion of how the current design overcomes obstacles of previous technology.

Evaluation Criteria

Your proposed solution will be evaluated on the following:

- A thermodynamic study of the design
- A cost/efficiency analysis of your design that provides a basis for comparing your design to traditional C-Si modules. Your LCOE should be based on a scale-up to a 100 MW array. The LCOE should follow DOE standards. Be sure to consider:
  - energy efficiency of a large-scale PV array (100MW), considering auxiliary power drains (if any)
  - the capital to construct a full-scale system of cooled PV modules
  - longevity of equipment and potential for equipment degradation (address replacement costs).
  - monitoring, maintenance, replacement, and related costs.
  - land space lost in the primary array due to equipment not ordinarily found in a PV array (if any)
  - other applicable costs
- Scale-up plans for the design that illustrates feasibility on a large scale (100 MW array)
- Discussion of advancements made over previous designs found in the literature
- Ability of your design to be self-sustaining and require little maintenance, monitoring, or replenishment.
- Discussion of all environmental products or wastes generated by your process
- An assessment of the ability to withstand normal weather conditions
- Technical fundamentals, performance, safety, and other issues
- Safety issues should be addressed in the Experimental Safety Plan (ESP).
- Originality, innovation, functionality, ease of use, maintainability, reliability, and affordability of the proposed technology
- How well the bench-scale represents your full-scale design concept
- Other specific evaluation criteria may be provided at a later date (watch the FAQs).

Each team is advised to read the Participation Guide for a comprehensive understanding of the contest evaluation criteria. For a copy of the Public Involvement Plan, Participation Guide, and other important resources, visit the WERC website: https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/.

FAQs/Deadlines

Teams are expected to watch for FAQs related to this task for important updates/answers to questions. The FAQs will be available online.

The Preliminary Design is due no later than 27 January, 2020.

The Experimental Safety Plan (ESP) is due no later than 24 February, 2020.

References

[1] T. J. Silverman et al., "Reducing Operating Temperature in Photovoltaic Modules," in IEEE Journal of Photovoltaics, vol. 8, no. 2, pp. 532-540, March 2018. DOI: 10.1109/JPHOTOV.2017.2779842

[2] L. J. Simpson, J. Woods, N. Valderrama, A. Hill, N. Vincent and T. Silverman, "Passive Cooling of Photovoltaics with Desiccants," 2017 IEEE 44th Photovoltaic Specialist Conference (PVSC), Washington, DC, 2017, pp. 1893-1897. DOI: 10.1109/PVSC.2017.8366065

[3] Zubeer, Swar A., H.A. Mohammed, and Mustafa Ilkan, “A Review of Photovoltaic Cells Cooling techniques,” 2017 ASEE E3S Web of Conferences, 22, 00205. DOI: 10.1051/e3sconf/20172200205

Awards

Each year, the WERC Environmental Design Contest and its sponsors award more than $25,000 in cash prizes. Successful completion of every stage of the design project qualifies each team for the following awards.

1. Task awards (First, Second, Third Place; minimum amounts: $2500-$1000-$500, respectively).
2. Freeport-McMoRan Innovation in Sustainability Award ($2500)
3. WERC Resources Center Pollution Prevention/Energy Efficiency (P2) Award ($500)
4. Judges’ Choice Award ($500)
5. Peer Award ($250)
6. Terry McManus Outstanding Student Award. (Minimum: $500, according to funding).

Award amounts listed are minimum amounts and may increase with available funding. Detailed award criteria: https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/