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Combined PV Cooling and Nighttime Power Generation through Smart Thermal Management of Photovoltaic–Thermoelectric Hybrid Systems

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Abstract : Photovoltaic (PV) cells, while pivotal for solar energy harnessing, confront a challenge due to the presence of persistent residual heat. This thermal energy poses significant obstacles to the performance and longevity of PV cells. Mitigating this thermal issue is imperative, particularly in tropical regions where solar abundance coexists with elevated ambient temperatures. In response, a sustainable and economically viable solution has been devised, incorporating water-passive cooling within a Photovoltaic-Thermoelectric (PV-TEG) hybrid system to address PV cell overheating. The implemented system has significantly reduced the operating temperatures of PV cells, achieving a notable reduction of up to 15 °C below the temperature observed in standalone PV systems. In addition, a thermoelectric generator (TEG) integrated into the system significantly enhances power generation, particularly during nighttime operation. The developed hybrid system demonstrates its capability to generate power at a density of 0.5 Wm^{-2} during nighttime, which is sufficient to concurrently power multiple light-emitting diodes, demonstrating practical applications for nighttime power generation. Key findings from this research include a consistent temperature reduction exceeding 10 °C for PV cells, translating to a 5% average enhancement in PV output power compared to standalone PV systems. Experimental demonstrations underscore nighttime power generation of 0.5 Wm^{-2}, with the potential to achieve 0.8 Wm^{-2} through simple geometric optimizations. The optimal cooling of PV cells is determined by the volume of water in the heat storage unit, exhibiting an inverse relationship with the optimal performance for nighttime power generation. Furthermore, the TEG output effectively powers a lighting system with up to 5 LEDs during the night. This research not only proposes a practical solution for maximizing solar radiation utilization but also charts a course for future advancements in energy harvesting technologies.

Keywords : photovoltaic-thermoelectric systems, nighttime power generation, PV thermal management, PV cooling
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