Advanced Computational Modelling of Photovoltaic Module Cooling for Improved Temperature and Efficiency Profiles

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Abstract

Thermal loading remains one of the key constraints limiting photovoltaic (PV) performance, particularly under high-irradiance conditions that elevate module temperatures far above ambient. This study presents a unified multiphysics framework for analyzing a crystalline silicon PV module subjected to three cooling strategies: natural air convection, forced air cooling and water cooling. A fully coupled 3D conjugate heat-transfer model was developed in COMSOL Multiphysics, with efficiency evaluated using a Python-based performance algorithm. Results indicate that natural ventilation reduces surface temperature by 3-6 °C, air cooling by 8-12 °C and water-based cooling by 14-20 °C at 1000 W/m² irradiance. In the presence of moderate wind, water-based cooling benefits further from evaporative heat transfer, suppressing module temperatures to near-ambient or sub-ambient levels and yielding absolute efficiency gains of 2–3%. Overall, the findings provide a physics-consistent comparison of cooling strategies and highlight hybrid evaporative cooling as a promising pathway for enhancing PV performance in hot, high-irradiance environments.

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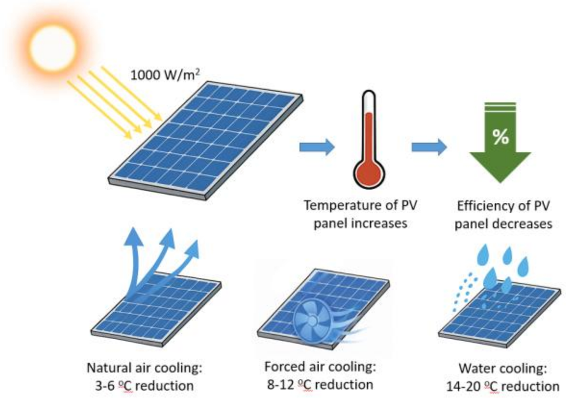

Innovative Description: Analysis of three cooling strategies is reported.