

Performance of a photovoltaic module with an integrated compound parabolic concentrator and a cooling system^{Author}

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Abstract

In recent years, Photovoltaic (PV) power generation has been receiving considerable attention as one of the promising energy alternatives for rural areas in developing countries. However, their widespread adoption has been hampered by the high capital cost and low conversion efficiencies of the available systems. Incorporation of a solar concentrator has been found by a number of researchers to increase the electrical power output of a PV module. However it exceedingly raises the module temperature, consequently lowering further its conversion efficiency.

The study was carried out to improve the conversion efficiency of an amorphous silicon PV module and to reduce the cost per unit output of the energy generated. This was done by incorporating a Cooling Unit (CU) and a Compound Parabolic Concentrator (CPC) to the PV module, forming a Combined Heat and Power (CHP) system generating electricity and hot water. By circulating a fluid with a lower inlet temperature at the back surface of a PV module, heat is extracted from the PV module, thus maintaining the module cell temperatures at a lower level. This improves the electrical conversion efficiency of the cells. The extracted heat can be directed into useful purposes. This forms a Combined Heat and Power (CHP) PV system. Use of low cost concentrators on a CHP system increases the radiant energy available per unit surface of the module resulting in lower cost per unit of energy generated.

Four experimental system were investigated: (i) Plain PV module (ii) PV module with cooling unit (PV/CU) (iii) PV module with a CPC (PV/CPC) and (iv) PV module with a CPC and a Cooling Unit

(PV/CPC+CU). Water was used as the cooling agent at a controlled flow rate. Three flow rates of

20 l/hr and 40 l/hr were tested in the study. Data collected were: current, voltage, solar radiation, ambient temperature, module temperature, and the inlet and outlet cooling water temperatures. A data logger (model Fluke 2286 series, U.K) was used to record data continuously at regular intervals from 9.00AM to 5.00PM. The power output, electrical and thermal efficiencies for the various study modules were computed and compared. Financial evaluation was performed by comparing the Levelized Energy Cost (LEC) of the systems tested.

The results obtained indicated that the cooling of a 51Wp PV module increases its electrical conversion efficiency. The PV module was cooled by an average of 14°C from 48.5°C to 34.4°C, which increased the electrical power output and efficiency by 45.6% and 37.5% respectively. Combined CPC and cooling showed better electrical performance on the PV system than either the CPC or cooling alone. In total, an integrated CPC/CU had the best performance at a cooling water flow rate of 40 l/hr, which increased the electrical power output and efficiency by 118.74% and 120.0% respectively in comparison to PV Plain.

The 25% truncated CPC also increased the thermal energy output of the combined heat and Power (CHP) PV system. The maximum thermal energy output was observed at a cooling water flow rate of 30 l/hr. At this point the thermal energy output was 3.018 KWh/day.

This study has shown that a CHP-PV system with added CPC increased the electrical power output of conventional PV modules with the benefit of generating useful heat energy in the process. These findings are important contributions in the research efforts aimed at increasing the acceptability and affordability of solar technology in the rural areas of developing countries.