Experimental Comparative Study on the Use of Photovoltaic Converters for Cooling Photovoltaic Modules

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Abstract The aim of this research is to study evaporative cooling as an effective method for cooling photovoltaic (PV) modules in the climatic conditions of Uzbekistan. The experiment was conducted during the summer period at the heliopolytechnic site of Tashkent State Technical University named after Islam Karimov. Among various cooling options for modules, evaporative cooling was selected as the most cost-effective and technologically simple solution for manufacturing and use. The principle of evaporative cooling of a wet object is based on heating and evaporating moisture using the heat of the cooled object. According to researchers, at an ambient temperature of 35-45°C, the maximum temperature of a photovoltaic module without cooling reached 66.1°C. The maximum temperature of the photovoltaic module with evaporative cooling was 46.8°C. Without cooling, the module's temperature would have reached 66.1°C. The reduction of the module temperature by 33°C demonstrates the effectiveness of evaporative cooling. Two photovoltaic panels with a power output of 290 W were used for the experiment. The difference in average electrical power between the uncooled PV module and the PV module with evaporative cooling was 23 W/h. The results indicate that evaporative cooling is indeed effective and can significantly reduce the power loss of PV modules due to overheating.

1 INTRODUCTION

Interest in non-traditional energy sources, particularly direct electricity generation from solar energy through photovoltaic converters (PVCs), is steadily increasing worldwide. Solar energy is one of the most widespread sources of environmentally friendly energy, reducing environmental impact and being applied in various fields [1-2].

Currently, the most common PVCs are made from silicon. Photovoltaic modules operate in open environments and are continuously influenced by weather conditions such as temperature, solar radiation, and wind [4-5]. The efficiency of most PVCs decreases as the temperature of the panels rises. With an increase in panel temperature, the already modest efficiency of PVCs declines further, raising the cost of generated energy. Published data suggest that a 1°C increase in panel temperature above the standard temperature of 20°C leads to a 0.45-0.50% decrease in efficiency [7-13].

However, various sources indicate that existing PVCs have relatively low efficiency, ranging from 12 to 16% [14]. These efficiency values are given for standard conditions, i.e., when the surface temperature of the solar panel is 20°C and the radiant flux density is 1000 W/m².

In hot climates such as Uzbekistan, where summer air temperatures often exceed 40°C, the efficiency of PVCs is significantly lower than 12-16% [15].

The proposed model involves studying evaporative cooling as an efficient method for cooling photovoltaic modules in Uzbekistan's climatic conditions. Among various cooling options, evaporative cooling was chosen as the most cost-effective and technologically simple method for manufacturing and use [16]. Experiments have shown that in conditions of hot climates, low ambient humidity, and wind, the wetting ability of gauze depends on the number of gauze layers due to capillary forces. Under these conditions, the water rise along the fabric reaches up to four layers of gauze, indicating that wetting is minimal due to the evaporation rate exceeding the water uptake rate via capillary forces. As the number of gauze layers increases, the height of water rise along the fabric also increases due to capillary forces.

The optimal number of gauze layers was found to be 10, providing the maximum water rise height, which enhances the efficiency of solar energy conversion into electrical energy. To maintain form and ease of use, the ten-layer gauze fabric was stitched together.

The proposed model is illustrated by drawings, with Figure 1 showing the general view of the photovoltaic converter and Figure 2 presenting view A, the rear side of the photovoltaic converter. The proposed photovoltaic converter consists of an aluminum frame (1), in which the photovoltaic module (2) is installed. On the rear side, there is an evaporative cooling system including a cotton element made of gauze fabric (4) consisting of ten stitched layers pressed by a metal mesh (5). A water reservoir (3) is located in the upper part.

Of the various cooling options for the modules, the evaporative cooling option was chosen as the cheapest, technologically easiest to manufacture and use [13].

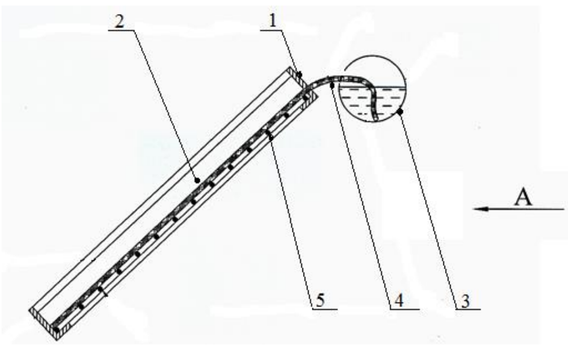

Figure 1: General type of the photoelectric converter.

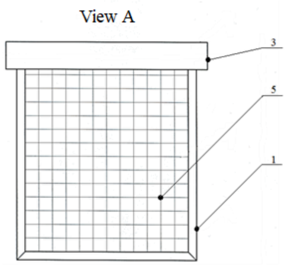

Figure 2: General view of the photoelectric converter, in (Figure 2) – view A.

A method of passive thermal regulation was developed in [16] using automated wetting of gauze fabric via water spraying to regulate the temperature of the photovoltaic module during operation. To verify the accuracy of the proposed theoretical calculations, experiments were conducted with a 290 W photovoltaic module, confirming its functionality. The results demonstrate that the developed cooling system reduced the photovoltaic module temperature by 12% and increased electricity generation by 14%. The main energy balance equation used for evaluating module temperature was applied to the photovoltaic module, showing strong agreement between theoretical and experimental values for both cooled and uncooled conditions.

2 MATERIALS AND METHODS

The photovoltaic converter consists of an aluminum frame housing the photovoltaic module, with an evaporative cooling system on the rear side. This system includes a cotton element made of ten stitched layers of gauze fabric pressed by a metal mesh. A water sprayer, controlled by an automation system, is located at the back of the converter. Water serves as the coolant, entering the water jet and exiting through inlet openings. A small pump inside the water storage tank directs the water to the mesh fabric. A thermal sensor was installed on the rear panel of the photovoltaic converter to measure the module's temperature. Figure 3 presents additional details of the system. The performance of the photovoltaic converter module is compared with that of conventional uncooled photovoltaic modules.

Figure 3: General type of photoelectric converter.

From Figure 4 it can be seen that the basic scheme of the photovoltaic converter consists of: 1 – photovoltaic module; 2 – water spray; 3 –

temperature sensor; 4 - manometer; 5 – water meter; 6 – check valve; 7 - pump; 8 – water tank.

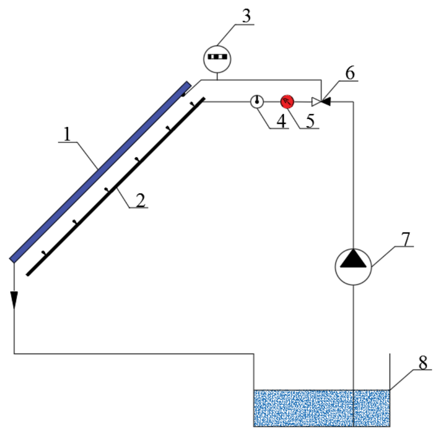

Figure 4: Principal scheme of photovoltaic converter.

The experiments were carried out from 06.05. to 03.09.2024 at the beginning of the summer season. Daily values of solar radiation, ambient temperature, PV temperature, relative humidity outside, etc. were measured.

List of instruments used for measurement;

- 1 FLIR E5 - to measure the temperature on the surface of the radiators;
- 2 anemometer AS856 - for measurement of wind speed and air temperature;
- 3 pyranometer Solar Power Meter Di-LOG SL101 - for solar radiation;
- 4 pressure manometer - for water pressure;
- 5 termometer with output sensor - for temperature measurements.

In particular, a multi-channel digital thermometer of the brand DS18B20 with portable temperature sensors, with a temperature range of -55°C to +125°C, was used to measure the temperature of the photovoltaic converter. The temperature measurement accuracy in the range from --10°C to +85°C is ±0.5°C.

3 RESULTS AND DISCUSSIONS

Increasing solar radiation intensity raises ambient temperature, which in turn increases the surface and rear side temperatures of the photovoltaic converter. The highest temperature was recorded on the surface of the photovoltaic converter due to direct solar exposure. Heat transfer occurs from the hot surface, directly exposed to intense solar radiation, to the cooler surface, leading to an increase in the temperature of the rear panel compared to the ambient temperature. At the start of the experiment, the surface temperature of the photovoltaic converter was 29.2°C, and the rear side (absorbing plate) temperature was 26.7°C. These temperatures gradually increased, reaching a maximum of 46.8°C at 12:20. The rear surface temperature was 33°C, as shown in Figure 5. Water sprayed onto the rear panel during active cooling reduced the module's temperature. The average temperature reduction of approximately 30% for the surface and rear panel of the photovoltaic converter, compared to an uncooled module, was attributed to heat transfer facilitated by the cotton element on the module's rear side.

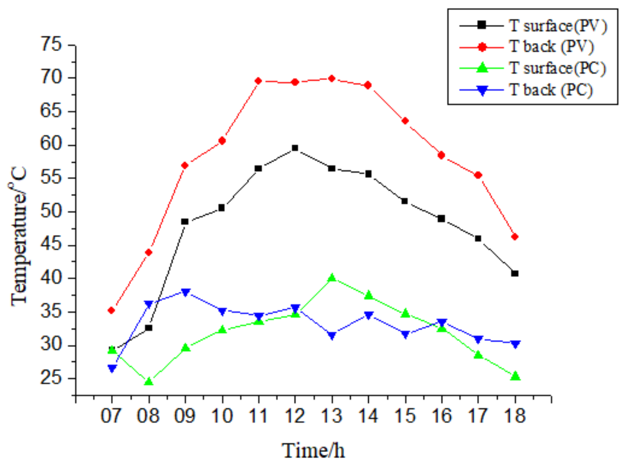

Figure 5: Temperature distribution on PV modules with cooling and without cooling.

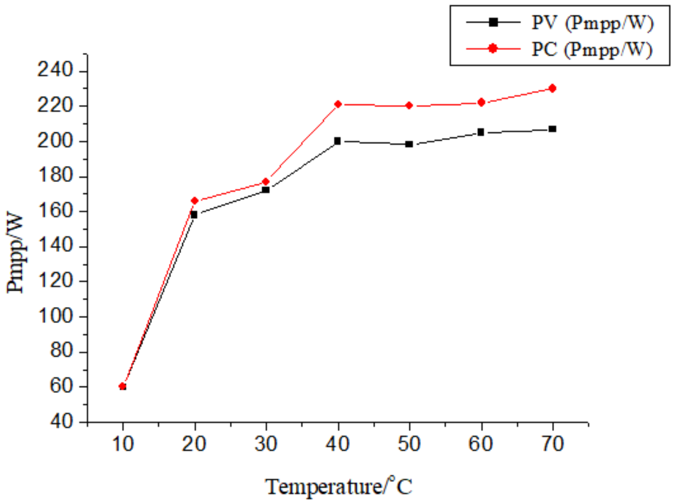

Figure 6: Performance of the photovoltaic module with cooling (PC) and without cooling (PV).

In the study, an infrared thermal imager (FLIR E63900) was used (Fig. 7).

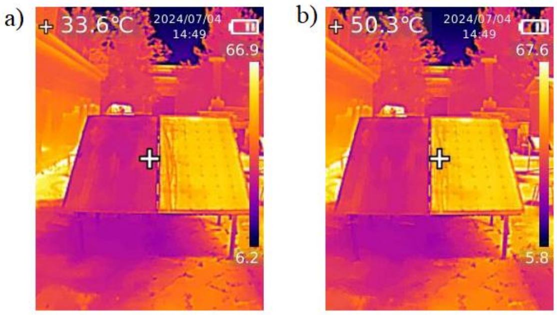

Figure 7: Dynamics of temperature change in of PV module with photovoltaic converter (a) and b without cooling.

4 CONCLUSIONS

The following conclusions can be drawn from the results of the studies:

1) At a photovoltaic layer temperature of 46.8°C, the efficiency reduction of PVCs does not exceed 5%. Throughout the experiments, the average efficiency reduction was no more than 5%.;
2) Experimental data indicate that lower air humidity and higher wind speeds enhance the effectiveness of evaporative cooling.;
3) Photovoltaic modules used without cooling in hot climates significantly degraded in performance.;
4) The applied cooling method is suitable for small-scale photovoltaic installations. Due to its effectiveness, the evaporative cooling method requires further research.

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