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Power output and efficiency enhancement of a Polycrystalline-silicon PV module using simple cooling methods

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ABSTRACT
To balance out energy derived from fossil fuels, solar energy applications continue to captivate the attention of the research community on a global scale. Employing photovoltaic (PV) modules to gather solar energy is one well-liked strategy. Solar panel power efficiencies deteriorate when temperatures rise during external installations. Therefore, there is a considerable amount of research being done on how to maintain temperatures as low as feasible. For a 50W polycrystalline silicon (Poly-Si) PV module, various cooling strategies have been investigated in this study effort. An experimental setup has been developed to conduct outdoor experiments on mostly sunny days. A data acquisition device was developed employing an ESP 32 microprocessor and various sensors for measuring various factors to assess power output and temperatures (current, voltage, and temperature). In this research, we explored two straightforward cooling techniques: forced air cooling with and without a designed finned heat sink, and natural air cooling. The maximum power output of the Poly-Si panel for natural air cooling is 40W, while the maximum peak power for forced air cooling is 42W. The efficiency of the solar panel for both natural and forced air cooling was calculated to be about 16%. The efficiency of the panel is also quite high in the range of 14-15.9% during the natural air cooling with the heat sink. It is worth noting that the highest efficiency is observed for the longitudinal forced air-cooling method (17.8%) followed by the transverse forced air cooling method with a marginally lower value of 17% employing the finned heat sink.

Keywords: Solar energy, Photovoltaics (PV) modules, Polycrystalline-Si, PV cooling.

1. Introduction

The limited supply of fossil fuels and Bangladesh's socioeconomic development make it difficult for scientists and researchers to meet the country's rising need for power while also reducing harmful emissions and protecting the natural environment. Renewable energy sources including solar, wind, biomass, and hydropower might potentially be used as alternatives to help Bangladesh and the rest of the globe deal with their current energy issue. In Bangladesh the present share of renewable energy to the total energy generation is only 1.45% where the major portion of total renewable energy (62.9%) is from solar energy [1]. The least amount of electricity is seen to be produced from renewable energy. Solar energy is the most abundant sources of renewable energy. It is one of the most potential renewable energies attracting significant drive to be harvested across the world. Due to the geographical location of Bangladesh, between 20.30-26.380 north latitude and between 88.04-92.440 east longitudes, it has a great potential to harvest solar energy [2]. More energy is obtained from sunlight striking the earth in a single hour than people use in a whole year [3].

Solar energy sources outperform both renewable and conventional sources of electricity. Generating electricity by harvesting solar energy directly through photovoltaic panels is considered one of the most promising and growing market in the field of renewable energy [4].

Solar cells, often known as PV cells, are electronic components that fundamentally transform solar energy from sunlight into electric energy. Moreover, the costs of Si-based solar panels have declined so rapidly that panel costs now make up <30% of the costs of a fully installed solar-electricity system [5]. The International Energy Agency (IEA) anticipates that by 2050, photovoltaics (PV) will contribute approximately 11% of the world's electricity, offsetting 2.3 Gt of carbon dioxide (CO2) emissions annually [6]. The ability to directly convert solar radiation into electrical energy makes PV modules one of the most environmentally benign and environmentally sustainable products are available. In practical reality, proximately 15–25% of the solar radiation received is converted to energy; the remaining is converted to heat [7].

It has been claimed that when module temperature rises, PV module efficiency falls [8-11]. Every 1 °C increase in module temperature is said to cause a 0.65% reduction in the PV module's power output [11]. Depending on the type of PV material used, the reduction in module efficiency ranges from 0.25% to 5% for every degree of heat [9, 12]. Due to these issues, it was noted that several studies [8–10, 13-16] investigated various cooling strategies, trying to cool PV modules using active and passive cooling approaches. Various materials, including aluminum, water with ice blocks, phase change materials, etc., were used in these research projects to enhance cooling effects.

It is still worthwhile to research the best cooling method for increasing a PV module's output power. Furthermore, the purpose of this study is to employ straightforward cooling strategies to investigate how temperature affects the output power of a popular Poly-Si PV module.

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2. Experimental details

Regarding solar modules to be sustainable and highly efficient, the degree of ambient solar irradiation is crucial. A Pyranometer (SP Lite2, Kipp & Zonen, Netherlands) interfaced with a Mooshimeter was employed to record experimental data in order to practically continuously monitor the sun irradiance (Mooshim Engineering, USA). With a resolution of 10 μV, the Mooshimeter was employed. Every 10 seconds, the sun irradiance was registered using a Mooshimeter that was Bluetooth-connected wirelessly to a android smartphone. The value of irradiance (E) in W/m^2 is determined using the equation below [17]:

$$E = \frac{U_{emf}}{S} \quad (1)$$

where, U_{emf} (μV) is the output voltage and S is the sensitivity of the Pyranometer (73.4 μV/W/m²).

On the roof of the academic building "C" at Shahjalal University of Science & Technology (SUST), Sylhet, an experimental setup has been constructed for evaluating solar photovoltaic panels. A specialized structure is formed that can tilt two solar PV panels at any angle lower than 90^0 and attach two solar panels simultaneously**.** To measure a combination of voltages, currents, and temperatures, a data recording device using an ESP-32 microcontroller (32 bit) was manufactured. The data logging device's block diagram is depicted in Fig. 1. The necessary short-circuit current and open circuit voltage were measured using current sensors and voltage sensors integrated with relay switches, respectively. Two temperature sensors were held in place on the back of the module by adhesive taps in two different locations. An SD memory card was connected to a data logging device to record all the data collected during the panel cooling tests.

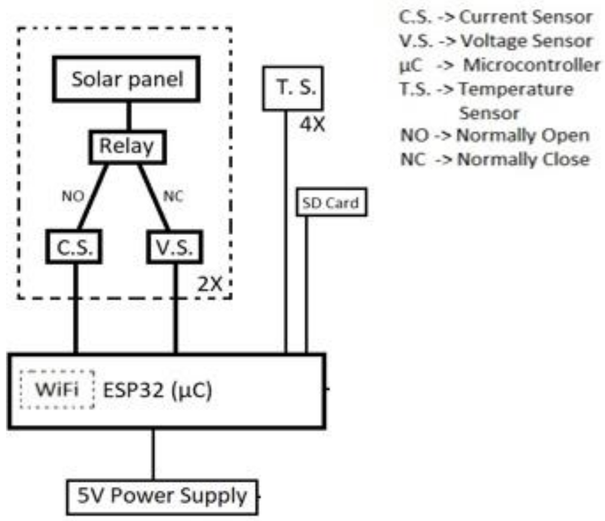

Fig. 1 Block diagram for the data logging device.

Fill Factor or FF is the ratio of PV module maximum power (P_{MPP}) with the product of short-circuit current (Isc) and open circuit voltage (Voc) and the other parameters can be seen as given in the following equations. The Fill Factor or FF and the efficiency of a PV module (η) are given as below [15]:

$$FF = \frac{P_{MPP}}{V_{OC} I_{SC}} \quad (2)$$

$$\eta = \frac{P_{MPP}}{E.A} = \frac{V_{MPP}.I_{MPP}}{E.A} \quad (3)$$

where, P_{MPP} stands for peak power point, E for solar irradiance, and A for PV module surface area. In this work, the instantaneous efficiency of a PV module has been determined for analysis.

In the present work, one polycrystalline Si module having a peak power of 50W as shown in Table 1 was used to investigate the effects of cooling on PV power output. The total cell area of the selected solar panel and its fill factor are 3.088×10^{-1} m^2 and 0.747, respectively. This study explored five alternative cooling methods. The first two cooling techniques investigated did not include a finned heat sink, but the last three did. Natural air cooling and forced air cooling are the first two methods.

Table 1 Specifications of the selected PV module.

Parameters	Typical values
Materials	Polycrystalline silicon
Size	720×540×30 mm
Peak power (W)	50
Voc (V)	21.60
Isc (A)	2.78
Vmp (V)	18.00
Imp (A)	3.10
Total area of cells	3.088×10^{-1} m^2
Weight (kg)	4.5
Typical filling factor	0.7470

The developed heat sinks as shown in Fig. 2 was clamped to the back of the chosen polycrystalline Si module and mounted longitudinally along a north-south direction. Natural air cooling forced air cooling along the transverse direction and forced air cooling along the longitudinal direction were the other three cooling methods used in conjunction with the finned heat sink. A forced air-cooling method was designed to contrast with the natural air-cooling method, as shown in Fig. 3. In this method, a standard electric fan was used to cool the module by moving surrounding air at a speed of 4-6 m/s. The fan, however, was not powered by the PV panel but rather by external electrical energy.

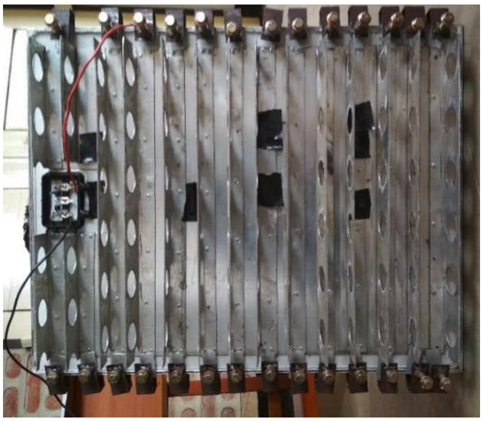

Fig. 2 The developed finned heat sink fitted on the back of the solar panel.

Fig. 3 Experimental setup for the forced air-cooling method.

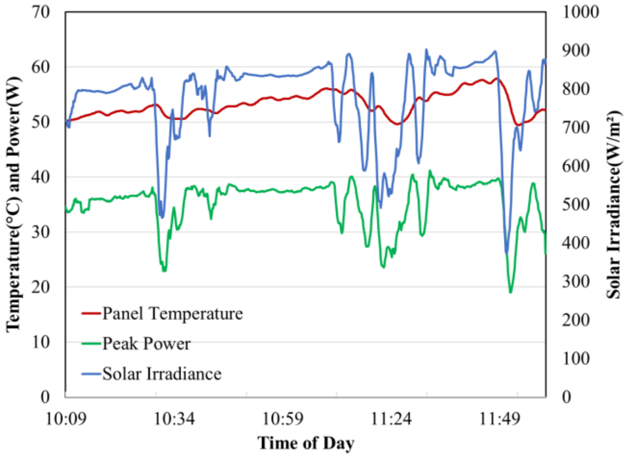

Fig. 4 Solar irradiance, panel temperature and peak power of the solar module during natural air cooling.

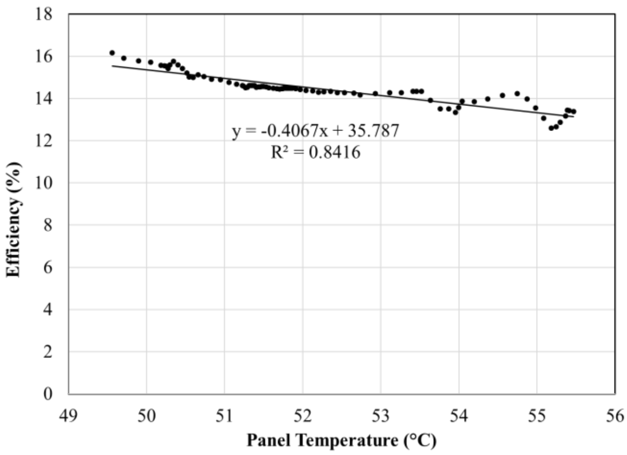

Fig. 5 Effect of panel temperature on the efficiency of the studied solar module during natural air cooling.

3. Results and Discussion

3.1 Natural air-cooling method

Fig. 4 demonstrates the variations in solar irradiance, panel temperature and power output for the Poly-crystalline Si module using the natural air-cooling method. The panel temperature is found to be in the range of 50-59°C. The amount of sun irradiation is proven to have a significant impact on peak power output. The figure also shows that the power output of the investigated solar module varies in accordance with the fluctuating solar irradiation. The peak power output of the solar panel is determined to be 40W. For the studied solar panel, Fig. 5 reveals a clear variation in efficiency with respect to panel temperature. The efficiency of the panel decreases as the temperature of the module rises. The efficiency of the Poly-Si panel is found to be between 14-16% for the temperature range of 49.5-56 °C.

3.2 Forced air cooling method

Forced air cooling was achieved by using an electric fan to move air longitudinally across the panel at a speed of 4-6 m/s. The fan was positioned in this cooling method so that roughly half of the air flow slides over the panel and the other half passes over the finned heat sink. Fig. 6 depicts the variation of solar irradiance, temperature, and power as measured during the experimental run. For this method, the panel temperature ranges 42-47°C for the studied solar panel. When compared to natural air cooling, the temperature of the Poly-Si panel is reduced by 16-20.3%. The power output is found to increase as the solar irradiation increases. The peak power of the Poly-Si panel is calculated to be 42W. The relationship between efficiency and temperature of the Poly-Si panel is shown in Fig.7. For the Poly-Si panel, the efficiency decreases very slightly from 15.8 to 15%. Due to its lower module temperature, natural air cooling has a marginally higher efficiency for the same intensity of solar irradiance.

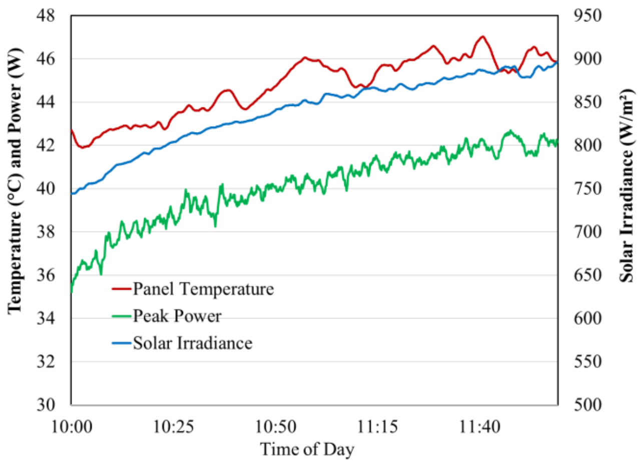

Fig. 6 Solar radiation, temperatures, and the maximum power output of the solar panels under forced air cooling.

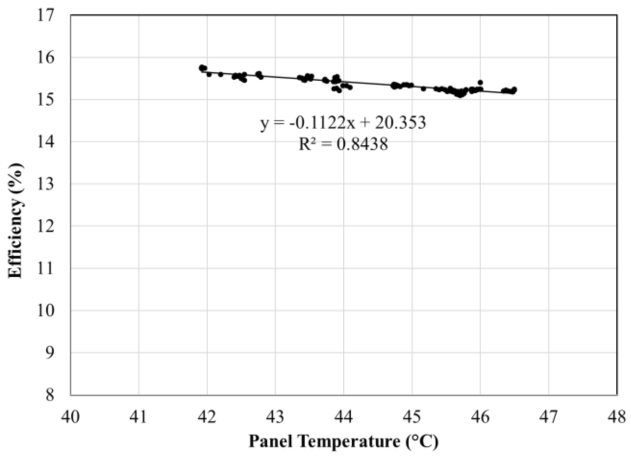

Fig. 7 The effect of panel temperature on the examined solar modules' efficiency during forced air cooling.

3.3 Comparison between natural and forced air cooling methods

Table 2 summarizes the effect of cooling on the power output and efficiency of the studied solar module using the natural and forced air cooling methods. The table shows that forced air cooling keeps panel temperatures lower than natural air cooling. The procedure of heat conduction and convection during different cooling procedures accounts for the observed temperature trends. The relative variations of peak powers for the different cooling methods are not only due to the efficiency fluctuation but also for the differences of solar irradiance during the test days. The higher values of peak power are particularly observed for the Poly-Si panel during the forced air cooling. The efficiency values are consistent with the observed peak power for the solar module. Because of the similar lower temperatures at the start of the experimental run, the polycrystalline Si panel has a similar peak efficiency for both cooling methods, with a maximum efficiency of about 16 percent. However, the efficiency drops more sharply for the natural air cooling that the other one. It may be due to the different ranges of panel temperatures at which the panel was running during the tests via the studied cooling methods.

Table 2 Summary of the effects of the conventional cooling techniques for the PV module.

	Natural air cooling	Forced air cooling
Panel temperature (°C)	50-59	42-47
Peak power (W)	40	42
Efficiency (%)	14-16	15-15.8
Efficiency deterioration rate (%/°C)	0.41	0.11

3.4 Natural and forced air cooling with the finned heat sink

Fig. 8 presents the variations in solar irradiance, temperature, and peak power for the Poly-Si module under the previously mentioned three cooling methods. The figure shows that the variation in panel temperature and peak power of the chosen module corresponds to the change in solar irradiance with respect to the time of day. The peak power clearly rises with the increasing solar irradiation supported by the summarized results in Table 3 The maximum peak power of 43W is observed for the forced air cooling along the transverse direction followed by a value of 40 for the forced air cooling along the longitudinal direction. However, the natural air-cooling method as a simplest technique shows quite a high value of peak power around 38W. The behavior of the panel temperature needs to be seen carefully in the above figure. With natural air cooling, the initial part of the temperature curve shows higher panel temperature because the delay of heat transmittance by the heat sink. After a while, the temperature of solar panels gets stable and fluctuates around 45°C, for most of the time, it is seen below this temperature. As a result, we can conclude that this passive cooling method is nearly equivalent to the forced air-cooling method without heat sink. The efficiency of the panel is also quite high in the range of 14-15.9% during the natural air cooling with the heat sink. It is worth noting that the highest efficiency is observed for the longitudinal forced air-cooling method (17.8%) followed by the transverse forced air cooling method with a marginally lower value of 17%.

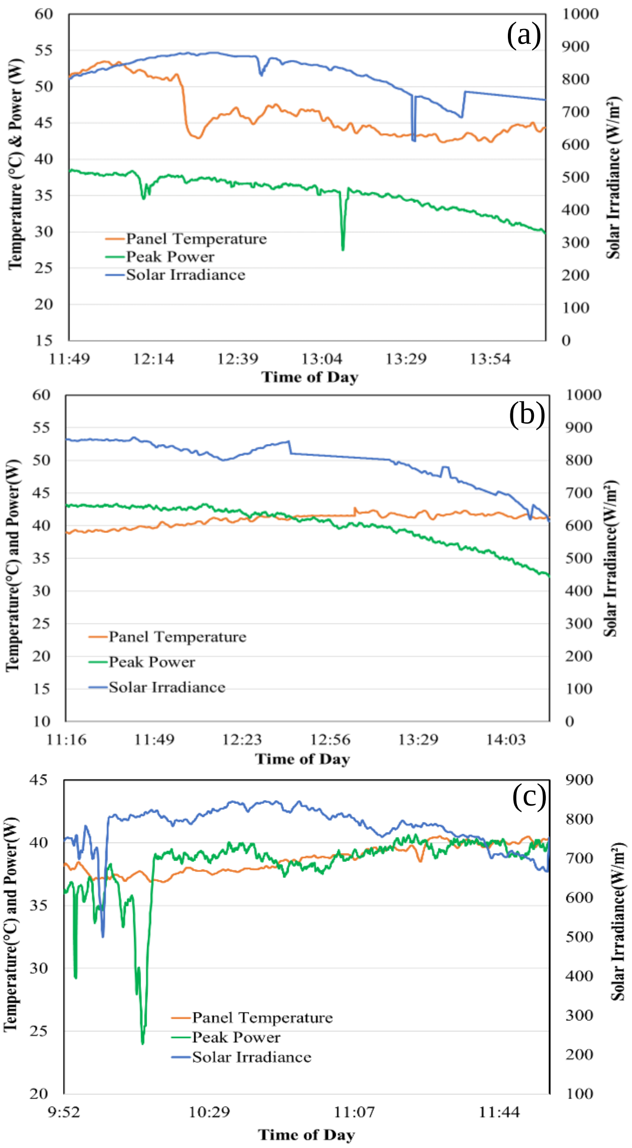

Fig. 8 Solar irradiance, temperatures and peak power for the Poly-Si module with the finned heat sink: (a) natural air cooling, (b) transverse air flow and (c) longitudinal air flow.

Table 3 Summary of the effects of the cooling techniques using the finned heat sink.

	Natural air cooling	Transverse forced air cooling	Longitudinal forced air cooling
Panel temperature (°C)	42-54	39-48	37-43
Maximum peak power (W)	30-38	32-43	24-40
Efficiency range (%)	14-15.9	16-17	15-17.8
Efficiency deterioration rate (%/°C)	0.16	0.11	0.47

4. Conclusions

To increase the power output of a Poly-Si solar module, five different cooling configurations were investigated. The peak power of the Poly-Si panel is found to be 40W for natural air cooling and 42W for forced air cooling. The maximum efficiency of the solar panel using both cooling methods was calculated to be around 16%. However, the rate of efficiency deterioration for natural air cooling is significantly higher than for forced air cooling. Using the finned heat sink, the maximum peak power of 43W is observed for the forced air cooling along the transverse direction followed by a value of 40W for the forced air cooling along the longitudinal direction. However, as the simplest technique, natural air cooling with a finned heat sink produces a high peak power of around 38W. The efficiency of the panel is also quite high in the range of 14-15.9% during the natural air cooling with the heat sink. It is worth noting that the highest efficiency is observed for the longitudinal forced air-cooling method (17.8%) followed by the transverse forced air cooling method with a marginally lower value of 17%.

5. Acknowledgement

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