

## Enhancement of Solar Panel Efficiency using Integrating Mirror-Based Solar Concentration and Passive Cooling Strategy

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### ABSTRACT

Solar photovoltaic systems are a pragmatic, scalable approach to capturing clean energy, providing a sustainable substitute for fossil fuel-derived electricity, and leading to a crucial element in the global shift to renewable energy. Significant emphasis is placed on improving the efficiency of solar panels. In this study, a mirror-augmented solar photovoltaic system was developed to absorb maximum solar radiation from the sun, and to lower the solar panel's temperature, a passive cooling mechanism was implemented. The modified system was incorporated with two mirrors aligned at an angle of 60° (approximately) relative to the PV panel surface on either side of the panel construction for solar radiation concentration. Fins made of aluminum were also embedded in the backside of the modified system to prevent solar panel damage due to excessive heat generation. A comparative investigation was conducted between a conventional solar photovoltaic system and a modified photovoltaic system. The typical conventional photovoltaic module produced a maximum current, voltage, and power of 1.24 A, 20.90 V, and 13.21 W, respectively, at a solar radiation level of 655.50 W/m<sup>2</sup>. Under identical solar radiation, the newly designed solar panel produced a maximum current and voltage of 1.47 A and 21.5 V and a power output of 16.75 W. The modified system exhibits a 27% improvement in output power compared to the reference one.

Keywords: Solar Energy, Photovoltaic Module, Renewable Energy, Solar Radiation, Passive Cooling.



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### 1. Introduction

The amount of energy consumption has increased all over the world. Currently, most of the world's energy demand is fulfilled by non-renewable energy sources. Non-renewable energy sources are either expensive or pollute the environment. Thus, the world is transitioning to renewable energy sources. Renewable energy sources are solar, tidal, wind, geothermal, hydropower, etc. Bangladesh has no geothermal source, and the scope for hydropower is quite limited. Tidal power has not reached a commercial state, and biomass requires substantial agricultural and animal waste. Solar energy is the most dependable renewable energy resource in Bangladesh. Solar photovoltaic systems are used to convert solar energy to electricity. It is one of the most widely used renewable energy sources in the commercial and residential sectors. However, they have a low conversion efficiency because only a small portion of radiation can be turned into electricity. Solar energy may be increased by the use of maximum power point tracking (MPPT), solar cell temperature regulation, solar panel dust removal, and mirror-augmented photovoltaic (MAPV) systems. [1].

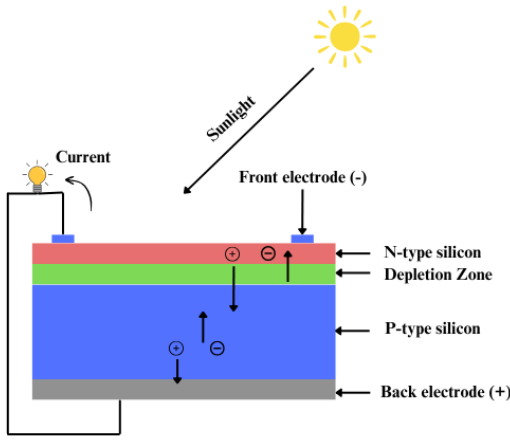
Arshad et al. [2] developed a photovoltaic system using a mirror concentrator with an active cooling mechanism and compared it with a system without reflectors and a cooling mechanism. Lin et al. [3] conducted an outdoor experiment as well as Matlab and TracePro simulation of a non-tracking mirror-augmented photovoltaic system producing 10% more power from mirror-augmented system compared to a regular one. Ahmad et al. [4] practically analyzed the performance of a passively cooled photovoltaic system and observed that the

heat sink improved the power by 14.2% compared to regular modules. Ibrahim et al. [5] conducted an experiment to find the optimum angle (30°) of reflective mirrors for maximum energy output and found out the energy output increased to 13.86% with water cooling and reflective mirrors. Johnston et al. [6] reported that incorporating 20 mm and 100 mm heat sinks increases the power output of photovoltaic module by 11.3% and 15.3%, respectively. Julajaturasirath et al. [7] incorporated four mirrors with a photovoltaic module to reflect more sunlight onto it, doubling the power output.

Earlier studies demonstrated simulations, solar reflector systems with active cooling, passive cooling alone, or just solar reflectors. In this research, a stationary (non-tracked) mirror-augmented photovoltaic (MAPV) system with passive cooling was developed. The proposed system was placed alongside a conventional one to show the potentiality of the proposed system. The research was conducted at Khulna University of Engineering & Technology, Bangladesh (latitude 22.9013, longitude 89.5025).

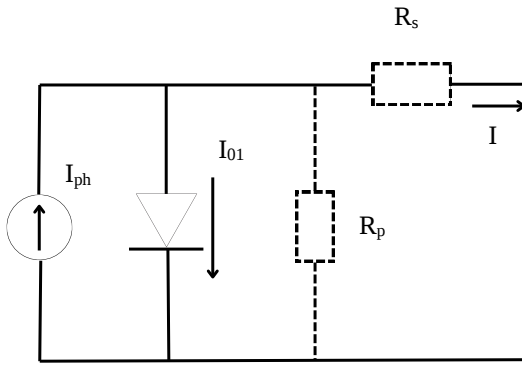
### 2. Basic Working Principal of PV Module

When sunlight falls on the surface of the PV panel, the photons with sufficient energy are absorbed, generating electron-hole pairs. Both current and voltage can be generated by separating electron hole-pairs. Fig. 1 shows the basic construction of a solar cell.



**Fig. 1.** Schematic diagram of the structure of a solar cell.

A p-n junction separates the electron and hole pairs, stopping the recombination process. The minority carriers travel to the p-n junction and diffuse across there, becoming majority carriers. The movement of charge carriers produces current that can flow through an external circuit. The photovoltaic effect produces the voltage. When light falls on the surface, the cells start to generate excess charge carriers. If these pairs are confined within the cell, electrons will accumulate on the n-type and holes will accumulate on the p-type side. This generates an electric field driving the diffusion of charge carriers. This process generates a voltage across the terminals [8]. Fig. 2 shows the equivalent ideal Photovoltaic Cell configuration.



**Fig. 2.** Equivalent Circuit for Ideal Photovoltaic Cell.

The ideal equation of a solar cell is given as [9].

$$I = I_{ph} - I_{01} \left\{ \exp \left( \frac{V + IR_s}{k_B T} \right) \right\} - \frac{V + IR_s}{R_p} \quad (1)$$

The efficiency for a cell is given by [10]:

$$FF = \frac{V_{oc} * I_{sc} * FF}{V_{oc} * I_{sc}} \quad (2)$$

$$\eta = \frac{V_{oc} * I_{sc} * FF}{P_{in} * A} \quad (3)$$

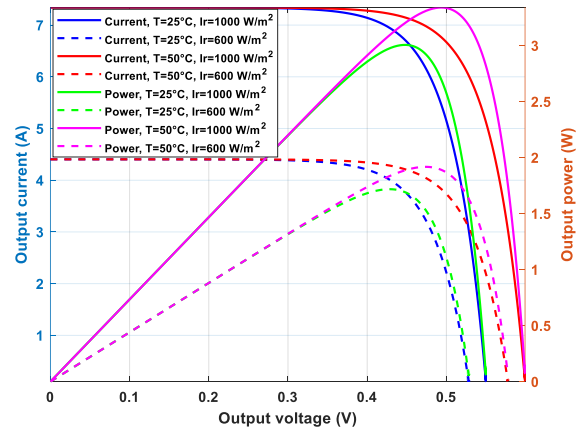
$$P_{max} = \left( \frac{\eta}{100} \right) * P_{in} * A \quad (4)$$

### 3. Factors Affecting Solar Module Output

Five key factors affect the power output of solar PV modules, as listed below:

1. The conversion efficiency ( $\eta$ )
2. The amount of light ( $P_{in}$ )
3. The operating temperature ( $T$ )
4. The solar cell area ( $A$ ), and
5. The angle at which daylight falls ( $\theta$ )

The output of the PV system mainly depends on irradiation and temperature of the solar module. So this research mainly focuses on the optimization of the maximum radiation and minimizing the effect of temperature on solar PV module. Fig. 3. Illustrates the Performance of Solar cell at different operating condition (pressure and temperature)



**Fig. 3.** Performance of Solar cell at different operating condition (pressure and temperature).

#### 3.1 The effect of irradiation ( $P_{in}$ ):

Irradiance is the measure of the amount of solar radiation from the sun falling on the surface. The current and voltage output of the PV module depends upon irradiance. The current generated by the PV module is directly proportional to irradiance, but the voltage generated is not affected strongly. Therefore, the power produced by the PV module is also proportional to irradiance. It is indicated in watts per square meter ( $W/m^2$ ). Ideally, its value is  $1000 W/m^2$ , but it greatly depends on output, which is proportional to the solar radiation. The power output and efficiency also depend on the solar radiation.

#### 3.2 Effect of temperature ( $T$ ):

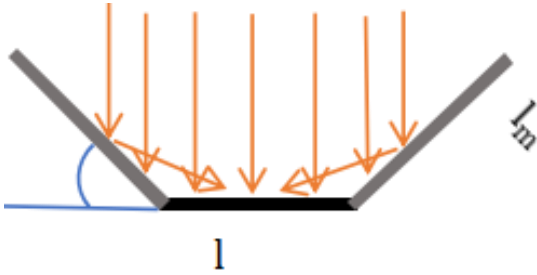
The ideal operating temperature for a PV module is  $25^\circ C$ . The increase in temperature from ideal conditions decreases the voltage output, leading to a decrease in efficiency and power output. For an ideal crystalline silicon PV module, the output voltage decreases by 0.35% for every degree rise in temperature. This is because increased temperature increases the resistance to the flow of current. The change in maximum voltage output and power output due to an increase in temperature is given as [11]

$$V_{max} = V_{max, (STC)} - (TC_{voltage}) \times V_{max, (STC)} \times \Delta T \quad (5)$$

$$P_{max} = P_{max, (STC)} - (TC_{power}) \times P_{max, (STC)} \times \Delta T \quad (6)$$

#### 4. Methodology

The mirror-augmented photovoltaic (MAPV) system has developed to receive the maximum solar radiation of a panel from the sun. Besides, aluminum fins are used to reduce the effect of temperature on solar panels; as a consequence, the efficiency of the module is risen. The following figure.4 shows a mirror-augmented PV system.



**Fig. 4.** Mirror augmented PV system

The inclination angle of the mirror with respect to the solar PV module can be calculated by the following equation:

$$I_m = \frac{-\cos 2\alpha_m}{\cos \alpha_m} I \dots \dots \dots (7)$$

From this equation, the approximate value for the inclination angle of the mirror was  $60^\circ$  [12]. Two reflective mirrors were fixed on both sides of a solar panel, and aluminum fins were attached to the bottom of the concentrated panel system for cooling purposes. Two of the solar panels (20W) were taken into account for the reference system and modified system to observe whether power was improved or not. Both of the systems were faced south with the help of a wooden stand. The magnitudes of solar irradiance are determined by a pyranometer.

##### 4.1 EXPERIMENTAL SETUP

The experimental setup is shown in Fig. 5 and Fig. 6. There had been several data taken during the experiment period, but only the few best results have been shown here. The solar panel was kept south-faced at an inclined angle of  $23^\circ$  with the horizontal. A wooden frame was designed for placing solar panels with two mirrors. The size of each mirror was 50 cm x 34.5 cm.



**Fig. 5.** Experimental setup



**Fig. 6.** Experimental setup

PV modules can be cooled down either in an active or passive cooling process. Active cooling requires external power, and passive cooling doesn't need any power source to cool down the module. Cooling is needed to decrease the surface temperature of the panel, increase the efficiency of the system, and prevent damage from overheating. In this research, aluminum fins were attached at the back of the panel to reduce extra heat.

##### 4.2 Necessary Components

**Table 1** List of components used in the proposed system.

| Components          | Specification                                                                             | Quantity |
|---------------------|-------------------------------------------------------------------------------------------|----------|
| Solar Module        | $I_{mp} : 1.11A$ ; $V_{mp} : 18V$<br>$P_{max} : 20W$ ; $I_{SC} : 1.71A$<br>$V_{OC} : 22V$ | 2 pcs    |
| Mirrors             |                                                                                           | 2 pcs    |
| Wooden stand        | -                                                                                         | 2 pcs    |
| Digital multi meter |                                                                                           | 2 pcs    |
| Pyranometer         | $11.8 \mu V/W.m^{-2}$                                                                     | 1 pcs    |
| Aluminum Fin        | -                                                                                         | 2 pcs    |
| Arduino Uno         | 5V                                                                                        | 1 pcs    |

**Table 2** Comparison of short circuit current between conventional and modified PV module.

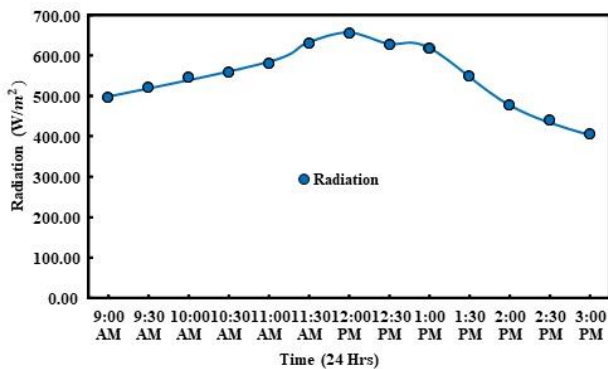
| Time     | Reference panel<br>Current ( $I_{SC}$ ) | Modified panel<br>Current ( $I_{SC}$ ) | Radiation |
|----------|-----------------------------------------|----------------------------------------|-----------|
| 9:00 AM  | 0.94                                    | 0.78                                   | 495.60    |
| 9:30 AM  | 0.97                                    | 1.00                                   | 520.00    |
| 10:00 AM | 1.02                                    | 1.12                                   | 545.00    |
| 10:30 AM | 1.05                                    | 1.18                                   | 559.50    |
| 11:00 AM | 1.19                                    | 1.41                                   | 581.50    |
| 11:30 AM | 1.22                                    | 1.45                                   | 630.50    |
| 12:00 PM | 1.24                                    | 1.47                                   | 655.50    |
| 12:30 PM | 1.23                                    | 1.40                                   | 627.50    |
| 1:00 PM  | 1.09                                    | 1.25                                   | 619.00    |
| 1:30 PM  | 1.08                                    | 1.14                                   | 550.50    |
| 2:00 PM  | 0.98                                    | 1.00                                   | 477.50    |
| 2:30 PM  | 0.86                                    | 0.78                                   | 441.50    |
| 3:00 PM  | 0.82                                    | 0.69                                   | 405.30    |

## 5. Result and Discussion

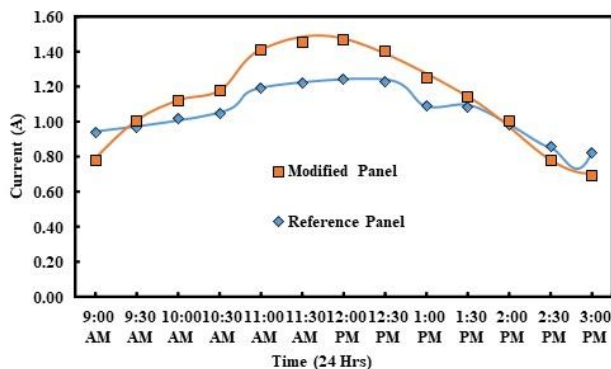
In this research, short-circuit current ( $I_{sc}$ ) and open-circuit voltage ( $V_{oc}$ ) were taken from the conventional and modified solar panels in both cooling and non-cooling systems. Also, the solar radiation was measured. The mirror's direction was fixed throughout the whole time.

**Table 3** Comparison of power between conventional and modified PV module.

| Time     | Reference panel<br>Power (W) | Modified panel<br>Power (W) | Improvement % |
|----------|------------------------------|-----------------------------|---------------|
| 9:00 AM  | 10.21                        | 8.76                        | -14.19        |
| 9:30 AM  | 10.64                        | 11.29                       | 6.08          |
| 10:00 AM | 11.30                        | 12.76                       | 12.96         |
| 10:30 AM | 11.52                        | 13.38                       | 16.18         |
| 11:00 AM | 12.99                        | 15.92                       | 22.51         |
| 11:30 AM | 13.06                        | 16.45                       | 25.91         |
| 12:00 PM | 13.21                        | 16.75                       | 26.81         |
| 12:30 PM | 13.04                        | 15.88                       | 21.79         |
| 1:00 PM  | 11.67                        | 14.11                       | 20.92         |
| 1:30 PM  | 11.62                        | 12.87                       | 10.76         |
| 2:00 PM  | 10.54                        | 11.24                       | 6.56          |
| 2:30 PM  | 9.21                         | 8.72                        | -5.26         |
| 3:00 PM  | 8.69                         | 7.68                        | -11.65        |



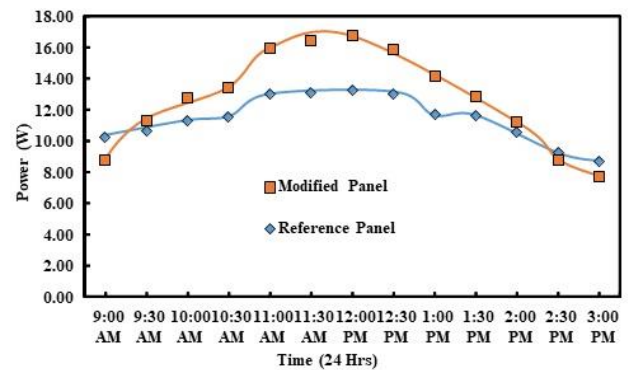
**Fig. 7.** Solar Irradiation vs. Time



**Fig. 8.** Short circuit current (conventional and modified PV module)

From the result, it can be seen that with the rise of solar irradiation, the output short circuit current rose with respect to time. There was a rise of solar radiation from 9 AM to 12 PM; after that, the radiation declined significantly. As a

consequence, the output power of the solar module increased from 9 AM to 12 PM, then the output power of the solar module decreased.



**Fig. 9.** Output power of solar PV module (conventional and modified PV module).

Arshad et al. [2] observed significant improvements in power output with the combination of mirror concentrators and an active cooling system. According to Ahmad et al. [4], passively cooled photovoltaic systems have increased power output by 14.2%. Johnston et al. [6] showed that heat sinks increased power by 15.3%, and Julajaturasirath et al. [7] also reported increases in doubling power by attaching four reflectors, respectively. This research demonstrated a 27% increase in power production, which surpasses the previous work's output.

## 6. Conclusion:

The present study developed a mirror-augmented photovoltaic system where two reflecting mirrors were attached to the solar panel to concentrate solar radiation. Also, aluminum fins were attached at the back of the panel to control the PV module temperature. Besides, this research compared the short-circuit current, open-circuit voltage, and output power of the photovoltaic module with the conventional PV module and modified panel. The maximum short circuit current recorded was 1.24 A and 1.47 A, respectively, from the conventional panel and modified mirror-augmented panel when the solar radiation was maximum. The maximum output power from the Regular reference panel was 13.21 watts, whereas the modified panel Provided 16.75 watts for radiation to 655 W/m² at 12:00 PM. The findings from the investigation demonstrate that the power output of the modified panel was enhanced by 26.71% compared to the reference panel.

## References

- [1] Mohammad Karimzadeh Kolamroudi, Mustafa Ilkan, Fuat Egelioglu, Babak Safaei, Maximization of the output power of low concentrating photovoltaic systems by the application of reflecting mirrors, Renewable Energy, Volume 189, 2022, Pages 822-835.
- [2] R. Arshad, S. Tariq, M. U. Niaz and M. Jamil, "Improvement in solar panel efficiency using solar concentration by simple mirrors and by cooling," 2014 International Conference on Robotics and Emerging Allied Technologies in Engineering (iCREATE), Islamabad, Pakistan, 2014, pp. 292-295.
- [3] W. C. Lin, D. Hollingshead, R. H. French, K. A. Shell, M. Schuetz and J. Karas, "Non-tracked mirror-

- augmented photovoltaic design and performance," 2012 38th IEEE Photovoltaic Specialists Conference, Austin, TX, USA, 2012, pp. 002076-002081.
- [4] Ahmad, E. Z., Sopian, K., Ibrahim, A., Gan, C. K., & Razak, M. S. A. (2022). Experimental investigation of passively cooled photovoltaic modules on the power output performance. *International Journal of Power Electronics and Drive Systems/International Journal of Electrical and Computer Engineering*, 13(1), 520, pp520-527.
- [5] Ateka K. Ibrahim, Omer K. Ahmed, Sameer Algburi, Optimum angle of reflective mirrors integrated on PV/Trombe wall: An experimental assessment, *Energy Reports*, Volume 10, 2023, Pages 591-603.
- [6] Ellis Johnston, Peter S.B. Szabo, Nick S. Bennett, Cooling silicon photovoltaic cells using finned heat sinks and the effect of inclination angle, *Thermal Science and Engineering Progress*, Volume 23, 2021, 100902.
- [7] S. Julajaturasirath, W. Jonburom, N. Pornsuwancharoen, The experiment of double solar energy by reflection light method, *Procedia Engineering*, Volume 32, 2012, Pages 522-530.
- [8] J. Yao and R. Zhang, "Analysis of structural characteristics and development trend of solar cells," 2022 International Conference on Applied Physics and Computing (ICAPC), Ottawa, ON, Canada, 2022, pp. 47-51.
- [9] Tom Markvart, Luis Castañer, Chapter IA-1 Principles of Solar Cell Operation, Editor(s): Augustin McEvoy, Tom Markvart, Luis Castañer, *Practical Handbook of Photovoltaics (Second Edition)*, Academic Press, 2012, Pages 7-31.
- [10] N. Reza and N. Mondol, "Design and Implementation of an Automatic Single Axis Tracking with Water-Cooling System to Improve the Performance of Solar Photovoltaic Panel," 2021 International Conference on Automation, Control and Mechatronics for Industry 4.0 (ACMI), Rajshahi, Bangladesh, 2021, pp. 1-6.
- [11] Chetan Singh Solanki," Solar Photovoltaic Technology and Systems-A Manual for Technicians, Trainers and Engineers," PHI learning private limited, Delhi, 2013.
- [12] B. Fortunato, M. Torresi, A. Deramo, Modeling, performance analysis and economic feasibility of a mirror-augmented photovoltaic system, *Energy Conversion and Management*, Volume 80, 2014, Pages 276-286.

## NOMENCLATURE

|                              |                                                                         |
|------------------------------|-------------------------------------------------------------------------|
| $\eta$                       | : Efficiency                                                            |
| $P_{\max}$                   | : Output power in watt (W)                                              |
| $P_{\text{in}}$              | : Light input per unit area ( $\text{W}/\text{m}^2$ )                   |
| $V_{\max, (\text{STC})}$     | : The PV module voltage at maximum power point at STC                   |
| $\text{TC}_{\text{voltage}}$ | : Temperature coefficient of voltage                                    |
| $\Delta T$                   | : The difference in operating PV module temperature and STC temperature |
| $P_{\max}$                   | : Module's maximum power output                                         |
| $P_{\max, (\text{STC})}$     | : Module power at maximum power point at STC                            |
| $\text{TC}_{\text{power}}$   | : Temperature coefficient of power                                      |
| $I_{01}$                     | : Saturation current of a diode                                         |
| $I_{\text{ph}}$              | : Photo current                                                         |
| $R_s$                        | : Series resistance                                                     |
| $A$                          | : Area of the solar cell                                                |
| $V$                          | : Voltage across the output terminal                                    |
| $K_B$                        | : Boltzman's constant                                                   |
| $T$                          | : Absolute temperature.                                                 |
| $R_p$                        | : Shunt resistance                                                      |
| $I$                          | : Current                                                               |
| $V_{\text{oc}}$              | : Open circuit voltage across the PV panel when current is zero         |
| $I_{\text{sc}}$              | : Short circuit current across the PV panel when voltage is zero        |
| $\text{FF}$                  | : Fill Factor                                                           |
| $V_{\max}$                   | : Voltage value at maximum power point                                  |
| $I_{\max}$                   | : Current value at maximum power point                                  |
| $l_m$                        | : Mirror width                                                          |
| $\alpha_m$                   | : Inclination angle of the mirrors                                      |
| $l$                          | : PV module width                                                       |