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Evaluation and Comparison of Performance of Solar PV cell in Different Configurations

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Abstract

This research paper proposes an unique originating design for generating more power by using plane mirror reflection of light propagating towards solar cells of solar photovoltaic systems and usage of air cooling to the PV cells when solar PV cells cross optimal temperature limit. This study provides novel methods for justifying this type of framework outline as well as preliminary findings about the use of a uni-directional reflectance function. In this study, the advantages of employing a plane mirror as a reflector for photovoltaic applications are quantified, as is the usage of a plane mirror in conjunction with solar PV cells that are exposed to air as a cooling medium. Shade, the sun's sporadic nature, and dust reduce the total quantity of incoming radiation on a PV panel, which affects the panel's efficiency. The impact of the aforementioned problems was minimized by the employment of a plane mirror, which ultimately increases radiation to the solar cells. When solar PV cells are exposed to both direct and reflected light at the same time, their temperature crosses the optimal temperature threshold and efficiency begins to decline. By using a cooling medium, efficiency may be increased once again. The performance of a silicon polycrystalline PV module with a mirror reflector and a solar cell with a plane mirror exposed to air as a cooling medium is experimentally measured, and its performance with and without the mirror are contrasted. The efficacy of solar PV cells with plane mirrors and solar PV cells with plane mirrors exposed to air as a cooling medium was evaluated by experimental observation.

Keywords

Photovoltaic; Reflector; Cooling Medium; Power Output, Performance Enhancement, Tracking system

1. Introduction

1.1 Background

Our daily life might be powered by solar energy to an amazing extent. One of the greatest renewable energy technologies that is both economical and environmentally good is the solar power system. Solar energy is a plentiful, eco-friendly resource that is accessible practically all year long and everywhere on Earth. Photovoltaic technology has recently taken on a significant position among alternative renewable energy sources, and research into these technologies is now continuing to grow.Organic semiconductor-based solar cell devices are appealing due to their light weight, mechanical flexibility, clean solar energy conversion, low cost of manufacture, and potential for mass production. [1].

Utilizing inexpensive light concentrators and reflecting mirrors, such as concentrator photovoltaic, is one simple technique to increase the performance of a PV system (CPV). Conventional manufacturing techniques provide low-cost production because reflecting mirror construction is minimally expensive and straightforward. Sunlight-based photovoltaic (PV) systems are a rapidly growing market for sustainable energy sources and will play a significant role in the future mix of economic energy [2], [3]. The majority of commercial and utility scale PV installations now exist as parallel columns of level modules that are oriented toward the mean maximum solar intensity [4]. The photons from sunshine are converted into electrons in solar cells using semiconducting materials like silicon (Si), the second most prevalent element in the world after oxygen.

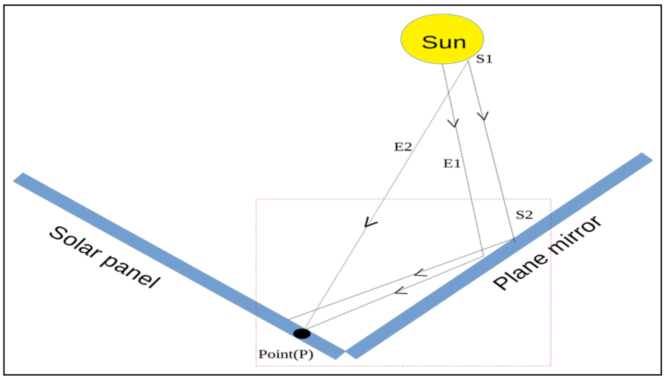

Figure 1: Theoretical setup to increase efficiency of PV cell

In the next energy age, solar photovoltaic technologies and systems are showing promise. 85 PW of the approximately 166 PW of solar energy that is produced each day is received by Earth. This demonstrates that not only does solar power output far exceed our present global 15 TW power consumption, but that all other sources produce electricity at rates well below solar power [5],[6],[7]. Direct radiation or beam radiation is referred to as the radiation that does not reflect or scatter and strikes the surface directly [8]. Diffuse radiation is the term for scattered radiation that strikes the ground. Concentration photovoltaic systems essentially have the job of collecting irradiation that does not reach the solar cells, including dispersed and beam irradiation.

2. Problem Statement

It was a better notion to do some experimental study on improving the efficiency of the solar PV panel because the typical efficiency of the solar PV panel was between 15 percent and 20 percent. Lower power output of solar PV cells in freshly installed solar street lamps, small and large solar power plants is a result of dust collection, shading, and cloudy weather.

There is a noticeable amount of dust buildup on the solar panels as a result of the high dust content in the atmosphere in many polluted regions. Street lighting is anticipated to be provided by solar technology for roughly 10 to 12 hours each day. It might not always be able to control the power for an LED bulb for that long due to a number of issues. To run consistently and flawlessly for the specified period of time, solar devices must have fully charged batteries mounted on the system. The quantity of irradiance is the main factor that regulates battery charging among a number of other elements that affect battery charging. Irradiance that is sufficient for charging the batteries might occasionally be insufficient in situations like shade and dust buildup.

In today's energy market, solar energy was essential, but solar PV panel efficiency needed to be increased. The goal of this research is to employ a plane mirror and air as a cooling medium to boost the efficiency of solar PV cells when their optimal temperature range is exceeded.

3. Research Objective

The main objective is to find out the performances of solar PV cell when solar PV cells, External plane mirror and cooling medium are used in different configurations.Among specific objective,First one is to find out the change in efficiency of solar PV panel when solar PV cell was subjected to plane mirror and cooling medium in different configurations, second one is to find out intensity of light which was utilized by solar PV cell to generate electricity when solar PV cells, External plane mirror and cooling medium are used in different configurations and third one is to analyze power output of solar PV cell vs. different time of radiation in each day when solar PV cells, external plane mirror and cooling medium are used in different configurations.

4. Literature Review

The cells in a PV module can be linked in series or parallel and enclosed in a laminate that is protective of the environment. PV modules are the fundamental component of PV solar systems. To create the configuration generating the necessary power output, modules can be joined to one another. For instance, a PV module made up of 90 solar cells may produce enough electricity to power tiny motors and charge batteries. Semiconductor materials are used to create photovoltaic panels. The difference between conductors, insulators and semiconductors are Conductors contain freely moving electrons,Insulators do not contain freely moving electrons and Semiconductors can have freely moving electrons under certain conditions.Conductors and insulators are sandwiched between semiconductors. As a result, semiconductors can serve as an insulator or a conductor, depending on their surroundings. Sunlight is a key factor in causing the semiconductor material of the PV module to act as a conductor.

The energy from the sun is transferred to the electrons, causing an electric current to flow. Silicon (Si) is a common semiconductor representative [9]. Since it is simple to manufacture silicon from sand, it is utilized extensively in the construction of solar panels. In general, silicon exhibits insulator behavior and does not have any free-moving electrons. Since there must be free electrons for current to flow, silicon in its native condition cannot be used to create PV generating units. Doping silicon with boron and phosphorous results in the free-moving electrons necessary for conductors. A solar cell is made of silicon that is both P-type and N-type mixed. While the P-type silicon makes up the side of the cell that faces away from the sun, the N-type silicon makes up the side that faces the sun.

A PN junction is created at the junction of a P-type and an N-type semiconductor. Due to the photo-voltaic effect, electricity begins to flow when a PN junction is exposed to sunshine [10],[11]. The mirrors (reflectors) are placed opposite the solar panels to send more light toward the modules in front of them. The light that hits them is reflected back toward the solar panels to produce more electricity.

Nigerian researchers Aliyu Abubakar and M.H. Ali did study on PV cells with plane mirrors in a 2017 and discovered that the addition of a plane reflector improved the efficiency of solar cells. They discovered that by utilizing a plane mirror as a reflector, the variation in power produced by solar cells may be brought into equilibrium when a plane mirror is present [12]. In 2017, Muhammad Bilal, Muhammad Naeem, Muhammad Zain, and Abideen Afridi conducted research on solar cells with plane mirror in Pakistan and discovered that using concentrator photovoltaic technology increased the output power and efficiency of solar panels (CPV)[13].

Through the use of an air-cooled heat sink approach, Popovici, Hudişteanu, Mateescu, and Cherecheş (2016) addressed the issue of decreased cell efficiency caused by overheating [14]. Even though Odeh and Behnia suggested using water cooling to increase efficiency (2009)[15].

5. Methodology

Identifying the place and position of the panels was a crucial step in designing a PV system as the later components have been streamlined to this step. A few concepts and tips had kept in mind while performing the site assessment are Shade Analysis, Sun hours, Panel tilt angle. The Mirror reflected solar panel was constructed using locally available raw materials to make it cost effective. At first the plane mirror was made attached to the solar panel with optimum angle. A frame was constructed to support the reflectors made to the sizes in appropriate standard.

The reflector was mounted on the frame that can slide in a horizontal as well as in a vertical axis. Considering the geometry and position of sun and proposed site, a PV module was kept inclined at 30 degree to horizontal axis. Solar panel was positioned to the north-south direction. The reflecting mirrors had to attach to the edges of the solar panel. The mirror was aligned in such a ways that maximum amount of sun radiation will be reflected over the solar panel. The cooling fan was provided as a cooling medium to PV panel.

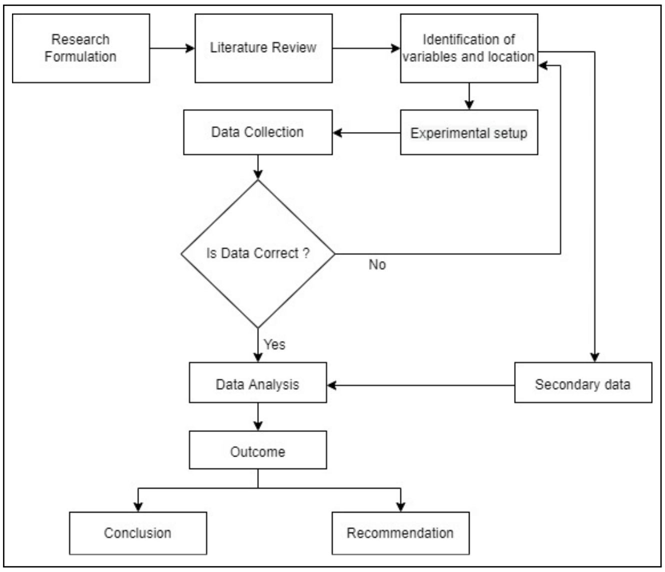

Figure 2: Data calculation and analysis flow chart

To run the experiment, the whole system was to be put under sunlight. At first, the open circuit voltage and short circuit current have to be measured as a data of tracking with reflection system. After that the mirror was closed by a cover of opaque material and data was taken as only tracking system. The mirror cover was again open and data were taken as tracking with plane reflection mirror, then the PV panel is subjected to air cooling medium and output voltage and current are to be measured. The experiments were conducted for a total of 15 days and the data were collected. Among them, data taken on fifteen days were presented in Table as representative. The table showed that open circuit (OC) voltage and close circuit (CC) current for various mode as: tracking only and tracking with reflection and Tracking with reflection with cooling medium.

The data obtained from the experiments on each day was calculated for various parameters like power from tracking system (PTS), power from tracking with reflection system (PTRS) and power from tracking with reflection subjected to cooling medium. Then a comparison was made between PTS, PTRS and PTRS with cooling medium. The power output was calculated for each experimental days and the data collected on experimental days for various modes as mentioned earlier were plotted as power versus time of the day. Among them the graphs for each day was presented.

In first case, data were taken when there were no plane mirror and cooling medium i.e. only power output of solar PV cells of normal conditions. Sun based PV cell was the essential gear for the experiment. Multimeter was utilized to get information precisely.

In second case, plane mirror was subjected to solar PV cells at appropriate angle and short circuit current and open circuit voltage were measured to calculate power output of solar PV cells with plane mirror. PV panel, plane mirror and multimeter were utilized for getting better power output. Whenever there was a high intensity of light then temperature of PV cells crossed the optimum temperature level so in order to keep the temperature of PV cells with in limit, air was subjected as a cooling medium.

In third case, plane mirror was used for reflection of sunlight over the PV panel and baltra fan was used for supplying air for cooling solar PV cells. Data acquired by utilizing digital multimeter.

Figure 3: Experimental setup for data observation for case 1

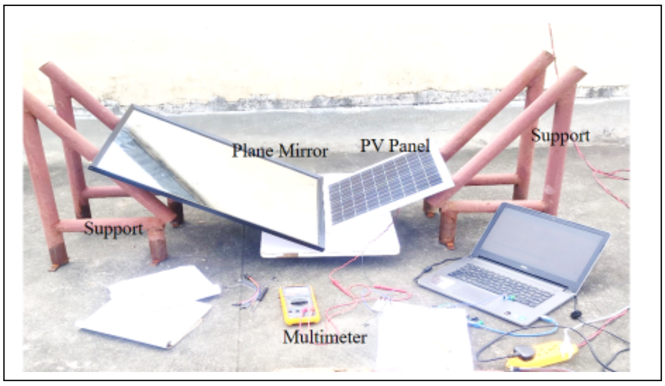

Figure 4: Experimental setup for data observation for case 2

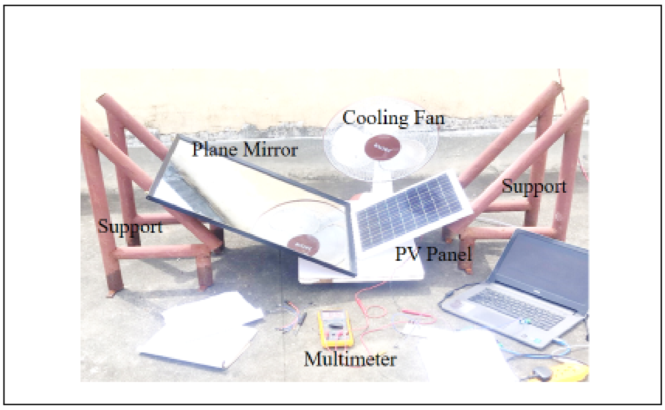

Figure 5: Experimental setup for data observation for case 3

6. Result and Discussion

The experimental data were taken in fifteen different days in between Jun 22, 2022 to August 5, 2022 in MSC hostel, Pulchowk campus - Lalitpur,Nepal. The coordinate was 27.67° N, 85.316°E. For this project, a solar panel of power 20 watts was used and whose inner length was 31.4 cm and breadth was 36.3 cm. The solar panel consists of 90 small cells called solar cells, each solar cell of length 3.9 cm and breadth 2.9 cm. For this purpose, It measure the area of panel (A=31.4 cm×36.3 cm=

1139.82 cm²) and area of each solar cell (a= 3.9cm×2.9 cm=11.31 cm²). For 90 solar cell, the total area was 90×11.31 cm² =1017.9 cm².

Area of panel = [Area of 90 solar cells + Area of cell cell gap + Area of column column gap - doubling portion]

= [1017.9+48.18+75.84-2.1)] cm².

= 1017.9 cm².

The plane mirror of area (l=55cm×58.5cm= 3217.5 cm²) as the concentrator was used. The mirror was inclined at 30 degree with horizontal surface. For the cooling purpose of solar PV cells, Baltra table fan was used. The fan was used in arrangement of solar cells with plane mirror for making case three. The fan was rotated at speed of 2000 RPM. The fan have three blade and approximately 2 kg weight. Fan was kept at a distance of 40 cm from a PV panel at 90 degree inclination from vertical straight line. AC source was used for running fan. During experiment the maximum temperature of solar PV cells raises up to 37 degree centigrade and fan was able to decrease solar cells temperature to 27 degree centigrade at peak temperature. Fan reduce the temperature of solar PV cells by 8 to 10 degree on average when running at full speed.

The graph in Figure 6 has been plotted by using the data observed in day 1, showed that the power of solar panel increases or decreases with respect to time, temperature and intensity of light. These data affected after [11:00AM] by seasonal clouds. The light gets intense after the mid-day. So, at [12:15 PM] the power recorded 11.19 watts without using plane mirror, When using plane mirror, the output power of solar panel increased to 12.88 watts and when air cooling medium was subjected to PV panel with mirror then power was recorded to 14.14 watts.

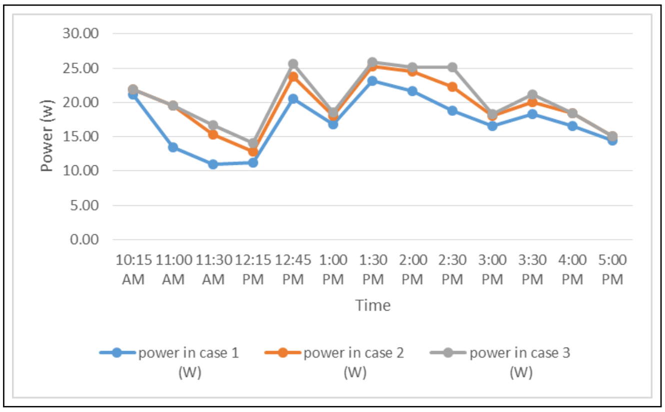

Figure 6: Power output of solar PV cells vs. different time of radiation in day 1

At [1:30PM] the power without mirror is 23.18 watts and power gets increased by using mirror to 25.23 watts and in case 3 the power was increased to 25.89 watts. Similarly, it showed that, as time increases the conditional powers decreases due to low intensity of light. At [1:00 PM] both conditional powers decreases due to low intensity light couldn't reach the panel because of seasonal clouds, as a result temperature of panel decreases. The graph between [1:30PM] to [2:30PM] was nearly constant for with and without mirror. The conditional power at [3:30PM] with mirror and fan was 21.15 watts, with mirror was 20.06 watts and with only PV panel up-to 21.15 watts and decreases slowly.

Average power produced in case 1 = $\frac{223.79}{13} = 17.21$ watts.
Average power produced in case 2 = $\frac{255.15}{13} = 19.63$ watts.
Average power produced in case 3 = $\frac{265.76}{13} = 20.44$ watts.

It was found that, the power produced with using mirror gets increased up to 14.01 percent by utilization of plane mirror as concentrator and the power produced with using mirror gets increased up-to 18.75 percent by utilization of plane mirror as a concentrator and air as a cooling medium. The efficiency of air cooling to the arrangement of PV panel with plane mirror was found to be 4.16 percent in day 1.The power difference and efficiency increment in each case was shown in table 1.

Table 1: Efficiency calculation in each case with data of day 1

S.N.	Condition	value
1	Average power differences in case 1 & case 2	2.41 watts
2	Average power differences in case 1 and case 3	3.23 watts
3	Average power differences in case 2 and case 3	0.82 watts
4	% increment in efficiency of PV by using mirror in case 1	14.01%
5	% increment in efficiency of PV when cooling medium was added in case 1	18.75%
6	% increment in efficiency when cooling medium was added in case 2	4.16%

In order to examine the nature of the conditional powers of solar cells, the currents and voltages of solar PV cells were measured for various time intervals on day 15 roughly one and a half hours before midday. The data are shown and calculated as powers lines in Figure 7.

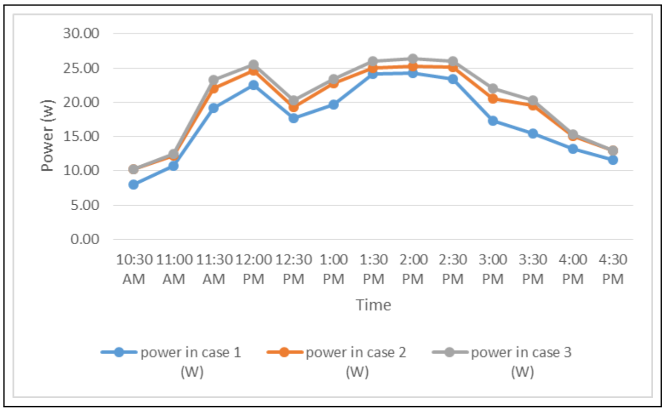

Figure 7: Power output of solar PV cells vs. different time of radiation in day 15

Before noon i.e. at [11:00AM], power of solar cells without a mirror was 10.68 watts, power of solar cells with a mirror was12.23 watts, and power of solar cells with a mirror exposed to air as a cooling medium was 12.42 watts. The power with mirror line fluctuated frequently as compared to the power without line. The maximum power for solar cell without mirror was 24.21 watts at [2:00PM], maximum power of solar cell with mirror was 25.24 watts at [2:00PM] and maximum power of solar cell with plane mirror subjected to air as a cooling medium was 26.33 watts at [2:00PM]. The minimum power for solar cells without mirror was 8.01 watts at [10:30AM], minimum power for solar cells with mirror line was 10.19 watts at [10:30AM] and minimum power for solar cells with plane mirror subjected to air as a cooling medium was 10.20 watts at [10:30AM].

The high intense light falling on solar cells cause the temperature rise and as a result it affects the power line to fluctuate frequently while the less intense light falling on the cell surface could not increase such high temperature. Temperature of solar cell decreases the output power of solar cell.

Average power produced in case 1 = $\frac{227.17}{13} = 17.47$ watts.
Average power produced in case 2 = $\frac{254.74}{13} = 19.60$ watts.
Average power produced in case 3 = $\frac{264.02}{13} = 20.31$ watts.

It was found that, the power produced with using mirror gets increased up to 12.14 percent by utilization of plane mirror as concentrator and the power produced with using mirror gets increased up-to 16.22 percent by utilization of plane mirror as a concentrator and air as a cooling medium. The efficiency of air cooling to the arrangement of PV panel with plane mirror was found to be 3.6 percent in day 15.The power difference and efficiency increment in each case was shown in table 2.

Table 2: Efficiency calculation in each case with data of day 15

S.N.	Condition	value
1	Average power differences in case 1 & case 2	2.12 watts
2	Average power differences in case 1 and case 3	2.83 watts
3	Average power differences in case 2 and case 3	0.71 watts
4	% increment in efficiency of PV by using mirror in case 1	12.14%
5	% increment in efficiency of PV when cooling medium was added in case 1	16.22%
6	% increment in efficiency when cooling medium was added in case 2	3.64%

The analysis was done from day 1 to day 15 in similar above mentioned procedure and the outcome of these analysis was summarized in table 3. Intensity of light was calculated as the ratio of power to the area of solar cells. The intensity of light Varies from morning to evening. As the day forward the intensity of light increases. At noon the intensity of sunlight is high because the light falls to the cells are exactly perpendicular. The data taken from multimeter varies due to temperature of cells, intensity and seasonal clouds. The relation between the intensity and temperature is inverse.

In day 5, the intensity of light with mirror was greater than without mirror. It was clearly observed that the intensity graph with time is similar to the power graph with time of day 5.

In day 10, it was observed that the intensity graph of solar cell with respect to time varies from 12:50PM to 3:05PM and the intensity of light was calculated by calculating the area of solar cells covered and current and voltage obtained from solar cell recorded on the multimeter for specific time. It was observed that, the intensity of light with time plotted on the graph alongside. The graph represents that the intensity of light with mirror to the solar cells is high than the intensity of light without mirror.

In day 12, the power of solar cell was calculated by multiplying the currents and voltages obtain for specific time. The graph of intensity was plotted by dividing the power calculated by area of solar cells .The plotted graph clearly shows that the intensity graph of intensity with mirror is high than the without mirror. The graph is similar to the power graph of day 12 with time.

In day 15, the intensity of light was observed and record the data of voltages and currents before nearly one hour of mid-day. The recorded data was plotted as line graph with time is similar to the power graph of day 15 with respect to time.

Table 3: Average increase in efficiency of solar PV cells in each case

Data taken in	% increment in efficiency of PV by using mirror in case 1	% increment in efficiency of PV when cooling medium was added in case 1	% increment in efficiency when cooling medium was added in case 2
Day 1	14.01%	18.75%	4.16%
Day 2	10.99%	13.93%	2.65%
Day 3	7.69%	10.89%	2.97%
Day 4	6.68%	10.47%	3.55%
Day 5	6.89%	9.33%	2.28%
Day 6	7.34%	10.33%	2.78%
Day 7	8.12%	11.72%	3.32%
Day 8	6.16%	8.94%	2.62%
Day 9	10.70%	15.84%	4.64%
Day 10	11.42%	16.28%	4.36%
Day 11	7.69%	10.00%	2.15%
Day 12	10.04%	12.50%	2.23%
Day 13	9.03%	11.86%	2.59%
Day 14	10.44%	12.98%	2.31%
Day 15	12.14%	16.22%	3.64%
Average	**9.09%**	**12.42%**	**3.04%**

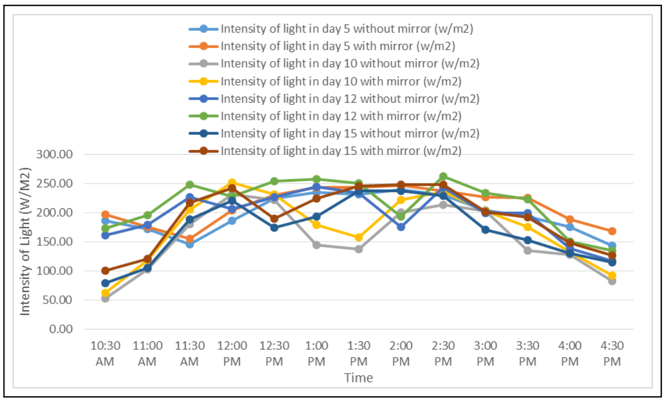

Figure 8: Intensity of light vs. time graph for day 5, day 10, day 12, day 15

7. Conclusions

This experimental study demonstrated how plane mirror concentrator may boost the effectiveness of solar PV panels. By employing a plane mirror as a concentrator, the average power generated without a mirror is boosted by up to 9.09 percent. This study shown that when solar PV cells with a plane mirror are exposed to air as a cooling medium, their performance increases by up to 12.42 percent. Adding an air cooling medium to solar PV cells with a plane mirror configuration resulted in an improvement in efficiency of 3.04 percent.

The experiment's findings showed that anytime the solar panel was exposed to both direct and reflected radiation, its temperature went over the optimal temperature value under bright lighting circumstances, and the panel's efficiency rapidly declined. In this case, using a cooling medium contributed to increasing the efficiency of solar PV cells. The employment of a plane mirror as a reflector might thereby lessen the impact of dust, snow, shadow, and irradiance variation. By employing a plane mirror as a concentrator, the average power generated without a mirror may be enhanced by a specific percentage. Industrial, agricultural, construction, educational, and domestic uses are all possible with this power.

References

[1] Mehmet Biber, Şakir Aydoğan, Zakir Çaldıran, Bülent Çakmak, Tevhit Karacalı, and Abdulmecit Türüt. The influence of annealing temperature and time on the efficiency of pentacene: Ptcdi organic solar cells. *Results in physics*, 7:3444–3448, 2017.

[2] Joshua M Pearce. Photovoltaics—a path to sustainable futures. *Futures*, 34(7):663–674, 2002.

[3] Kadra Branker, MJM Pathak, and Joshua M Pearce. A review of solar photovoltaic levelized cost of electricity. *Renewable and sustainable energy reviews*, 15(9):4470–4482, 2011.

[4] Chris Deline, Aron Dobos, Steven Janzou, Jenya Meydbray, and Matt Donovan. A simplified model of uniform shading in large photovoltaic arrays. *Solar Energy*, 96:274–282, 2013.

[5] Derek Abbott. Keeping the energy debate clean: How do we supply the world's energy needs? *Proceedings of the IEEE*, 98(1):42–66, 2009.

[6] Peter E Glaser. Power from the sun: Its future. *Science*, 162(3856):857–861, 1968.

[7] Blanca Mendoza. Total solar irradiance and climate. *Advances in Space Research*, 35(5):882–890, 2005.

[8] Hossein Mousazadeh, Alireza Keyhani, Arzhang Javadi, Hossein Mobli, Karen Abrinia, and Ahmad Sharifi. A review of principle and sun-tracking methods for maximizing solar systems output. *Renewable and sustainable energy reviews*, 13(8):1800–1818, 2009.

[9] M Parans Paranthaman, Winnie Wong-Ng, and Raghu N Bhattacharya. *Semiconductor materials for solar photovoltaic cells*, volume 218. Springer, 2016.

[10] AL Fahrenbruch and RH Bube. " foundamentals of solar cells". academic press, new york, 1983.

[11] Larry D Partain and Lewis M Fraas. *Solar cells and their applications*. John Wiley & Sons, 2010.

[12] Aliyu Abubakar and MH Ali. Performance improvement of photovoltaic module using plane mirror.

[13] Muhammad Bilal, Muhammad Naeem Arbab, Muhammad Zain Ul Abideen Afridi, and Alishpa Khattak. Increasing the output power and efficiency of solar panel by using concentrator photovoltaics (cpv). *International Journal of Engineering Works*, 3(12):98–102, 2016.

[14] Cătălin George Popovici, Sebastian Valeriu Hudişteanu, Theodor Dorin Mateescu, and Nelu-Cristian Cherecheş. Efficiency improvement of photovoltaic panels by using air cooled heat sinks. *Energy Procedia*, 85:425–432, 2016.

[15] SD Odeh, M Behnia, and GL Morrison. Hydrodynamic analysis of direct steam generation solar collectors. *J. Sol. Energy Eng.*, 122(1):14–22, 2000.