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Efficiency enhancement of solar cell using mirror concentrator

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Abstract

This research is done to find out a method by which the efficiency of a solar cell can be increased by using mirror concentrator to get a higher power and optimum efficiency. At first the sun lights are incident on the mirror concentrator made of plane glass and then the reflected rays are incident to the solar cell. Flat mirror concentrator (FMC) has been used to increase the incident irradiance on solar panel system by concentrating the sun light ray on it and then to improve the cell performance. A comparison is made for the same PV solar panel systems using single and triple flat mirror concentrator. It is a beneficial and important theory of solar power plant sector. It can be used in household and any kind of industrial area. The FMC consists of two flat mirrors made of glass, with dimensions (170cm × 80cm) enclosed by aluminum frame and inclined to an angle 55 ° with a solar panel (160cm × 120cm) tilted at 45° from the horizon. The results indicated that when the concentrator is used with the solar panel the efficiency increased by a factor of 4.52% to 11.34%. So, the increase in efficiency of the solar cell is 6.82%.

Keywords
Mirror concentrator, Reflected ray, Solar cell, Efficiency, Inclined Angle, Power.

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1 Introduction

Solar panels will play a major role in future sustainable energy production, but they work best when sunlight hits them directly. This can be a problem when sunlight is diffused by cloud cover or the sun moves overhead throughout the day. Many solar arrays actively rotate toward the Sun to capture as much energy as possible. This makes them more expensive and complicated to build and maintain than stationary ones. The negative aspects of fossil fuels and non-renewable energy sources are being increasingly scrutinized due to their harmful effects on the environment. This impact has been exacerbated by the rapidly changing nature of the Earth's climate in recent years, and more effort than ever is being put into renewable energy technologies in an effort to phase out non-renewable technologies and prioritize renewable energy sources. Among all renewable energy sources, photovoltaics (PVs)

– commonly known to the public as solar cells – are one of the most widely researched and deployed technologies due to the abundance of sunlight that hits the Earth every day. Depending on what they are made of and how they are constructed, PVs can have a range of functions for converting sunlight energy into electricity. However, if they are to be realized as a primary energy source in the future, their efficiency must be increased to offset the loss of energy generated from non-renewable sources. One way to increase the efficiency of PV is to use photovoltaic/solar concentrators. However, as with most components in technology, there are many different types, all of which have different advantages and disadvantages. Regardless of the type, the general principle of a solar concentrator is that it is an optical element (be it a lens, curved mirror or a flat mirror) that can be used to condense the light entering the PV, making it more efficient and converting sunlight into electricity. Concentrator is a recent discovery that has a unique geometry that is attractive for solar electric generation systems needing concentration. Since the Industrial Revolution, energy demand and economic growth have taken off simultaneously [1]. Numerous renewable energy sources are being researched by various countries to meet the demand for energy [2]. Research on solar energy is being conducted rapidly [3, 4]. Sustainable and green energy solutions are a recent method of making this planet cleaner and safer. Electrical energy share has been gradually enlarged and currently stands at 20% [5]. RERs (Renewable Energy Resources) have attracted a market, and various RER-based models have been developed [6]. There have been varying behavioral trends and levels of social acceptance of RERs [7–9]. RERs mainly consist of solar, wind, biomass, and hydro energy, which are freely available primary sources, in contrast with traditional fossil fuels. They are free from toxic or hazardous flow gases, making them more viable and greener. Wind energy has been utilized to meet energy needs, but has limitations of cut-in, rated, and furling wind speed, which vary depending on the location. Earth receives an amount of solar energy which is 6000 times greater than human energy needs [10]. Solar energy has dominated the energy sector as a long-lasting technology compared to other resources. It is also projected that we will achieve zero CO_2 emissions by 2050 [11]. In this research, a comparison is made for the same PV solar panel systems using single and triple flat mirror concentrator. It is a beneficial and important theory of solar power plant sector. It can be used in household and any kind of industrial area. The FMC consists of two flat mirrors made of glass, with dimensions (170cm $\times$ 80cm) enclosed by aluminum frame and inclined to an angle 55 $^\circ$ with a solar panel (160cm $\times$ 120cm) tilted at 45° from the horizon. The results indicated that when the concentrator is used with the solar panel the efficiency increased by a factor of 4.52% to 11.34%. So, the increase in efficiency of the solar cell is 6.82%. An important advantage of using of flat mirror concentrator is that, they are cost-effective and available in the market. It is making the usage of solar panel more feasible in developing countries of the world reducing the overall cost of electricity generation and improving the efficiency by PV solar system. Another advantage, is the easy installation of this system. As output of average power has increased considerably during mid-day using mirrors, so the panels which are equipped with mirrors are also able to be used for those equipments which require high rating power inputs during that part of the day time. But cleaning of the concentrator on regular basis is a must.

2 Literature Review

In 2023, N. S. Buktukov et al. [12] researched-on determination of the electrical characteristics of the solar cell inside the solar cells. The paper presents the results of experimental studies of a solar panel with a holographic concentrator and photovoltaic cells based on gallium arsenide. The high efficiency of converting solar energy into electrical power is shown when dispersing and focusing different wavelengths on a photocell. During elaboration of the obtained volt-ampere characteristics of solar photovoltaic conversion elements, which determine the output power of the photovoltaic panel, the high potential of the developed design of the photovoltaic panel has been revealed.

In the year of 2022, M. Singh et al. [13] made a study to create more electricity by employing mirrors to collect more solar radiation as well as sunlight to Photovoltaic cells. This improves the amount of energy that can be generated by a certain region of solar cells. The purpose of the study is to evaluate whether or not a simplified mirror technique can improve the performance of a solar cell, to determine the aspects of a solar cell that can be improved using simplified mirror techniques, and to confirm that the solar cells' performance has improved as a result of the simplified mirror techniques. The use of reflectors that are flat in form allows for an extra level of sunlight concentration to be achieved on the surface of the solar panel.

In 2021, A. Shariah et al. [14] established a design containing construction, installation and testing a stationary (non-tracking) concentrating system in Irbid, Jordan. Bifacial solar cells are used in the design. Two concentrator designs (with the same concentration ratio) are experimentally tested. Conc-A has a parabolic shape in the lower part but flat reflecting walls, whereas Conc-B has a standard compound parabolic shape in all parts. The receiving solar cells are arranged in three distinct positions in each concentrator. The results reveal that the output power from both concentrators is affected by the placement of the receiving solar cells within the concentrator. It has also been found that concentrators with flat reflecting walls perform better than those with parabolic reflecting walls. Conc-A's power collection is ~198% greater than that of a non-concentrating device. When Conc-B is used, the increase in power is ~181%.

During the age of 2019, F. Sh. Zainulabdeen et al. [15] focused on developing a method of evaluation the effect of concentrator on the solar panel performance to get a higher power and optimum efficiency. The results indicated that when the concentrator is used with the solar panel the efficiency increased by a factor of (51%) to (64%) and the variation in efficiency () is (25.4%), the variation in maximum output power (Pm) is (17%) and all solar parameters increased.

In 2016, Dr. Ali H.AL-Hamadany et al. [16], they studied on two flat glass mirrors that was used as concentrator of solar panel system. The mirrors increase's the concentration of sun light ray on the solar module. Anew model of solar panel system is designed by mean of software Zemax in order to find best possible inclination angle of the concentrator that improves the performance of the solar panel. So, the efficiency is 59.5% for designed system with inclination angle 60° of the concentrator.

In the year of 2015, M. Bilal et al. [17] This paper presents the comparison performance of a PV module without reflecting mirror and with reflecting mirror and manual tracking. The values of short circuit current and open circuit voltage were measured under different conditions of tracking. The output power was calculated and the values were obtained for different combinations. Findings from the experiments present that through using concentrators, a 25% mean rise of short-circuit (Isc) currents with sun tracking, can be achieved. Results also show that PV module with only tracking gives higher output than the system without tracking but the system with reflecting mirror and tracking gives greater output power.

In 2013, Basavaraj et al. [18] had a power shortfall of 70,000 megawatts while using 600.6 million kWh of energy. There were about 300 million people in India who did not have access to power. In December 2013, there was a power shortfall of 6,120 MW in south India.

2.1 Solar Panel

Solar panels are nothing but an electrical device which can transfer the light energy into electrical energy. Solar panels absorb the sun's rays and convert them into electricity or heat. A solar panel is actually an assembly of solar cells, which can be used to generate electricity through photovoltaic effect. These cells are arranged in a grid-like pattern on the surface of solar panels. It can also be described as a set of photovoltaic modules, mounted on a structure supporting it. Solar cells are produced depending on Silicon diffusion process. Installation of solar panels in homes results in combating the harmful emissions of greenhouse gases. Thus, solar cell helps to reduce global warming also [19, 20]. Solar panels do not lead to any form of pollution and are clean. They also decrease our dependence on fossil fuels which are limited and traditional power sources. A PV system was tested in Ghardaia that produced 12.91% and 20.89% more energy using single- and dual-axis solar tracking, respectively [21].

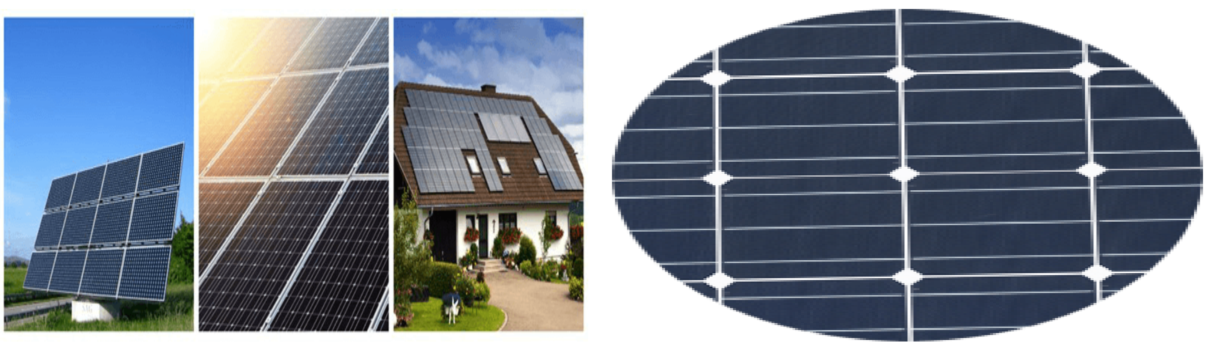

Figure 1: Monocrystalline Solar Panels.

A mathematical model of a dual-axis solar tracking system was tested for the partial CPV technology that achieved satisfactory performance in comparison with a non-tracking system [22]. The layers are arranged in such a way that the highest energy band gap material is placed at the top, while the lowest band gap material is placed at the bottom. MJ junction solar cells have a higher efficiency compared to single-junction cells. In a five-junction cell achieved efficiency of up to 40% [23].

2.2 Concentrator

The concept of Concentrator photovoltaic (CPV) is to use optical devices technically to concentrate the sunlight on small and efficient photovoltaic solar cells. Hence, the cost will be reduced by means of replacing the cell surface by the less expensive material used for the optical devices (glass, silicon. etc.) therefore the technology has great potential for cost reduction [24]

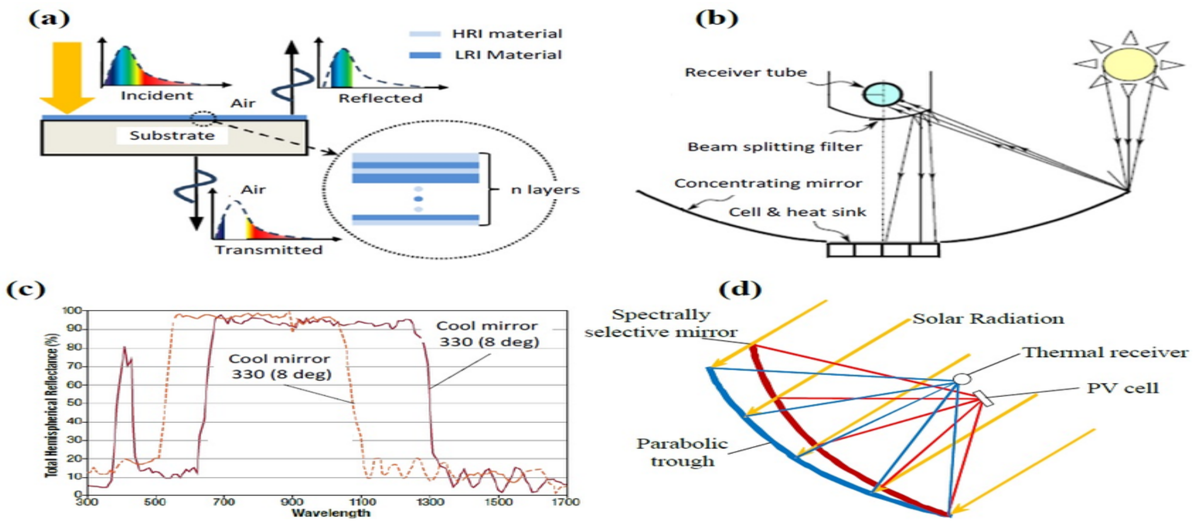

Figure 1: Diagram of Mirror Concentrator working.

Solar concentrators can also be used to melt materials and enforce heat engines. In the seventeenth century, lenses or burning glasses were the dominant form of concentrator. In the eighteenth and nineteenth centuries, the most popular concentrators were cone- shaped or parabolic reflectors. In the early twentieth century, many large solar energy projects used parabolic trough reflectors. Today's concentrators for photovoltaic system still have these basic forms. Bulk lenses, however, have been ruled out because of weight and cost, and are usually replaced by thin Fresnel lenses [25]. The structures and theory of concentrator solar cells are basically no different from those of non-concentrator cells, there are some subtle differences in the theory, but they can be ignored for simplicity [26].

$$P_{in} = I \times A \quad (1)$$

$$\text{Efficiency } \eta = P_{out} \div P_{in} \quad (2)$$

where Pin is the incident power of the sun and can be calculated from multiplying the (I) solar irradiance in (W/m^2) by the area of the solar cell or module (A) in square meter unit. The aim of this research is to improve the performance efficiency and reduce the cost of PV module by using a Flat Mirror Concentrator with the solar panel system to decrease the price of the electricity production.

3 Material and Methods

mirror concentrator was used on a rooftop where the sunlight was sufficient targeting to enhance the efficiency of solar cell to complete this research. All the arrangements was done for measuring the length and width of the solar cell and also for the concentrator. Flat mirror concentrator (FMC) has been used to increase the incident irradiance on solar panel system by concentrating the sun light ray on it and then to improve the cell performance. A comparison is made for the same PV solar panel systems using single and triple flat mirror concentrator. It is a beneficial and important theory of solar power plant sector. It can be used in household and any kind of industrial area.

The FMC consists of two flat mirrors made of glass, with dimensions (170cm × 80cm) enclosed by aluminum frame and inclined to an angle 55 ° with a solar panel (160cm × 120cm) tilted at 45° from the horizon. The mono crystalline silicon wafer was used for fabricating the solar cell in this research. The starting material was p-type silicon wafer. The weight and average thickness of the raw silicon wafer were 6.47 gm and 182.5 m respectively and the crystal orientation was (100). The steps of producing the solar cell were Cleaning, Texturing, Edge Isolation and doping. In diffusion process, the technology used for the doping method was phosphorus diffusion. In this research the solar panel had a Solar Length = 0.16 m and Solar Width = 0.12 m. Some people use the same principle when they use a magnifying lens to focus the Sun's rays on a pile of kindling or paper to start fires.

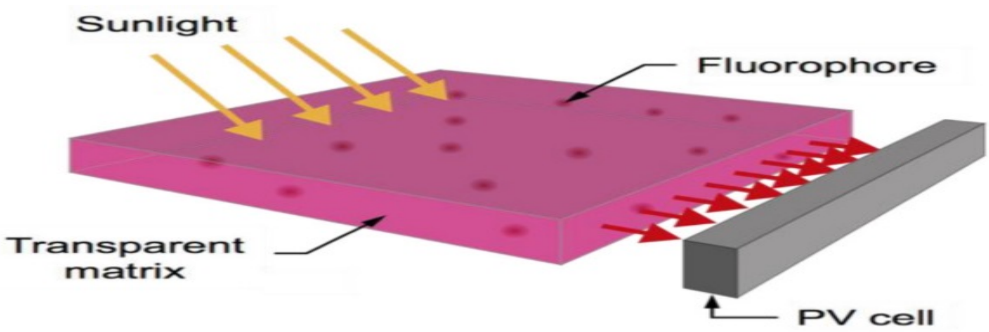

Figure 2: Working principle of Luminescent solar concentrators (LSC).

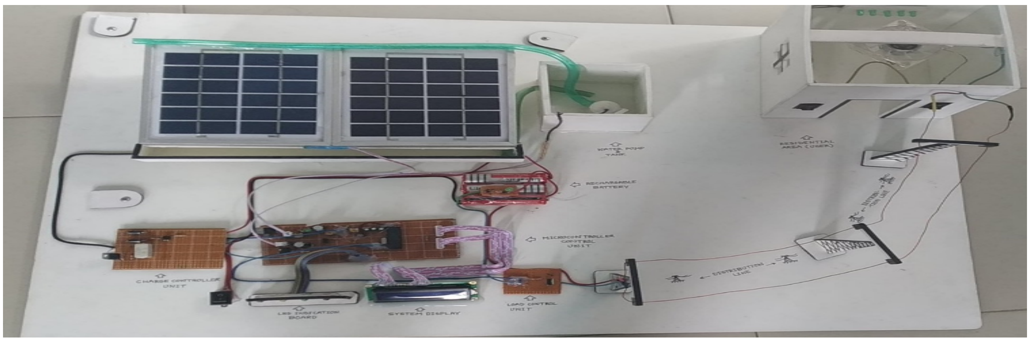

Figure 3: Image view of the research work.

As the solar concentrators follows the sun, the sun lights fall on the reflective concentrator and reflects the concentrated solar power onto a receiver. The advantage of using a solar concentrator is that it can provide a high solar electricity.

4 Results and Discussion

4.1 Results

This research is done for a 10 W solar cell (with efficiency 3.90%) before and after using mirror concentrator by two steps. Atfirst single mirror was used as concentrator for the solar cell and the efficiency was found 4.52%. After that three mirrors were used as concentrator and then the efficiency was found for the same solar cell 11.34% which is the proof of efficiency enhancement using mirror concentrator.

We know,
Efficiency $\eta = P_{out} \div P_{in}$

Now, $P_{out} = V\times I = 15 \times 0.6 = 0.9$ watt

$P_{in} = 1000\ Wm^{-2} \times (\text{Length} \times \text{Width})$

where Solar Length = 0.16 m and Solar Width = 0.12 m

So, Efficiency $\eta = P_{out} \div P_{in} \times 100 = 0.9 \div (1000\times 0.16\times 0.12) \times 100 = 4.52\%$

Again, Voltage V = 10.22 V, Current I = 0.2208 A

So, $P_{out} = 10.22 \times 0.2208 = 2.257$ W

And $P_{in} = 1000\ Wm^{-2}$

Efficiency $\eta = (2.257 \div 19.91) = 11.34\%$ (where solar width = 19.91 m)

4.2 Discussion

The experiment was done repeatedly within sunlight where the sunlight was available. From the result and calculation, it is obvious that if mirror concentrator can be used industrially for a solar panel, then the efficiency can be found in a high percentage. As the number or area of the concentrator is increased then the efficiency is increased also. If the area of concentrator can be increased providing the scope to receive a large amount of light, the output efficiency can be increased also. In future this research can be extended by increasing the number of the concentrator whether the efficiency enhancement is occurred or any other changes are found. It can also be done further by applying this experiment for various type Concnetrator.

5 Conclusion

A mirror concentrator was used on a rooftop where the sunlight was sufficient targeting to enhance the efficiency of solar cell to complete this research. All the arrangements was done for measuring the length and width of the solar cell and also for the concentrator. The results obtained show that, use of plane mirror for improving the performance of the solar panels have shown impressive results. An important advantage of using of flat mirror concentrator is that, they are cost-effective and available in the market. It is making the usage of solar panel more feasible in developing countries of the world reducing the overall cost of electricity generation and improving the efficiency by PV solar system. Another advantage, is the easy installation of this system. As output of average power has increased considerably during mid-day using mirrors, so the panels which are equipped with mirrors are also able to be used for those equipments which require high rating power inputs during that part of the day time. But cleaning of the concentrator on regular basis is a must. The results indicated that when the concentrator is used with the solar panel the efficiency increased by a factor of 4.52% to 11.34%. So, the increase in efficiency of the solar cell is 6.82%. As the number or area of the concentrator is increased the efficiency is increased also. It can also be done further by applying this experiment for various type Concnetrator.

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