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Effect of light concentration by flat mirror reflectors on the electrical power output of the photovoltaic panel

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Renewable energy area is gaining more prominence in recent times. In particular, conversion of solar energy in to electricity by using PV Panel has attracted significant researchers. In this work, the effect of light concentration by reflectors and inclination of PV panel on power output of PV panel has been investigated. Flat mirror reflectors were fixed to PV panel to increase the light intensity. The panel was kept either horizontally or at 30° inclination to horizontal. The effect on I-V curve, power curve, fill factor and efficiency are discussed. A significant improvement in short circuit current, power and a small increase in efficiency is perceived with the introduction of reflectors.

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1. Introduction:

Renewable energy sources are those sources which are continuously replenished by natural processes. Solar energy, biomass energy, wind energy, hydro energy etc.are some of the examples of renewable energy sources. The majority of the renewable energy comes either directly or indirectly from sun. Currently, renewable energy sources are being given more prominence as a result of depleting fossil energy sources and increasing environmental awareness.Among the various methods of generating electric power by alternative resources, photovoltaic (PV) technology has grown steadily in recent period as sunlight can be directly converted to electrical energy without causing environmental pollution [1 - 3]. Apart from generating electricity, solar energy has a vast area of applications such as water heating, lighting, and crop drying. The various solar devices can be either active or passive depending on the way they detain, convert and distribute solar energy [4]. The intensity of solar radiation reaching earth surface is estimated to be 1369 W/m^2 and is generally referred as Solar Constant [5].

A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. It consists of multiple components such as photovoltaic modules, mechanical / electrical connections, mountings and regulating devices. PV cells are made of semiconductor materials, such as silicon, cadmium and tellurium (CdTe), Gallium Arsenide (GaAs) [6 - 8].

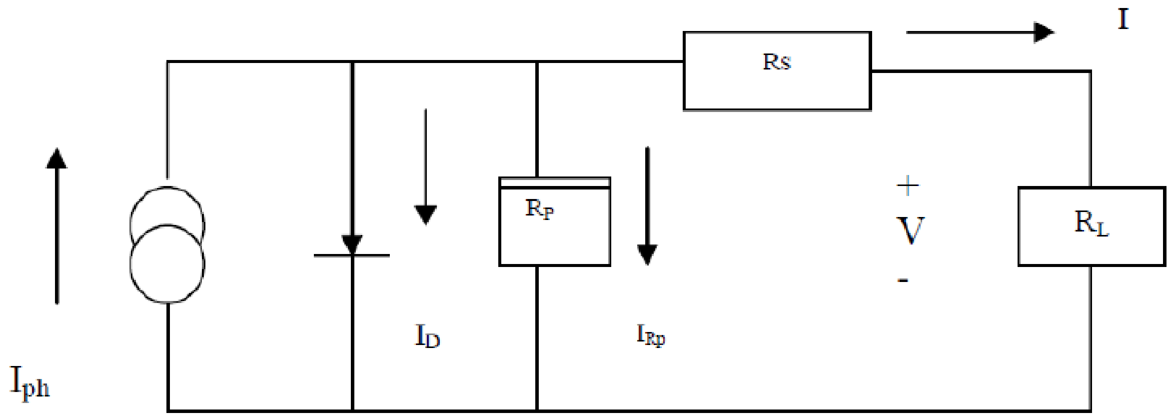

Figure 1: Equivalent circuit of a PV cell

An ideal PV cell is modeled by a current source in parallel with a diode. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the PV cell diagram in Figure (1). R_S is the intrinsic series resistance whose value is very small. R_P is the equivalent shunt resistance which has a very high value [5].

The efficiency of a PV cell is defined as the ratio of peak power output to input solar power and is calculated as:

$$\eta = \frac{V_{mp} \times I_{mp}}{I \times A}$$

where, V_{mp} is the voltage at peak power, I_{mp} is the current at peak power, I is the solar intensity per square meter and A is the area on which solar radiation falls. The efficiency will become highest, if the PV cell delivers maximum power for the right combination of environmental conditions of irradiance and temperature.

PV cell arrays are emploed concentrators in order to increase the effective irradiance.A concentrator captures solar energy in the large area and focuses it onto a small areawhere the solar cells are mounted. The ratio of the above two areas is called concentration ratio. A typical solar concentrator unit consists of a lens or mirrors to focus the light, anoptical trackingsystem to collect the solar energy from dusk to dawn and a cooling mechanismto dissipate excess heat produced by concentrated sunlight on the solar cells. Thisprocess leads to greater power falling on the area of focus thereby increasing efficiencyof conversion. Initial solar concentrators were of very low efficiency (4 % – 5 %) where as present day concentrator configurations offer significantly higher efficiency [9].

The simplest type of concentrating collector is the mirror-boosted, flat plate collector in which the concentration effect arises mainly from the increase in direct radiation reaching the absorber plate. Often, number of collectors are combined in two or more rows and set apart in N-S directions to allow for the additional sun shading caused by the mirror extensions.

In the present work, the effect of flat plate reflectors on the performance of PV module has been investigated.

2. Experimental:

A PV panel [Table (1 and 2)] was mounted on a rectangular steel frame and the assembly was fixed to a pin joint (provided with a graduated angular scale) which could be used to fix the panel at any angular position with respect to horizontal. The set up, in turn, was mounted on a bearing so that it can be rotated with respect to vertical axis. Polycrystalline silicon solar cells are used in the investigation. The cells were inserted within an encapsulation with an air gap in between.

Table (1): General Specification of PV panel

Company	**KotakUjra Pvt. Ltd.**
Model No.	KM 0010
No of cells	36
Dimension	445mm x 280mm x 30mm
Weight	1.5 kg
Cell material	Polycrystalline silicon

Table (2): Electrical specification of the PV panel

Sl. No.	**Item**	**Value**
1	Open circuit VoltageV_{OC}	21.24 V
2	Short circuit I_{SC}	0.59 A
3	Maximum voltage V_{mp}	17.64 V
4	Maximum Power at STC P_{max}	10 W
5	Maximum system voltage	600 V
6	Operating Temperature /Humidity	-40°C to +85°C

Detachable reflector assemblies of rectangular (445 mm x 342 mm) and square (280 mm x 280 mm) geometry were provided to the steel frame to study the effect of reflected light on the power characteristics of the panel. The reflectors were made up of glass back coated with mercury. Figure (2) shows the photograph of the actual experimental set up.

(a) Panel at horizontal position **(b) Panel at 30° inclination**

Figure (2) : Experimental set up

The current and voltage developed by the PV panel exposed to sunlight were measured using ammeter, voltmeter and resistance load regular intervals. A time of about 6 - 8 minutes was required to complete one trial.

The experiments were conducted under following four conditions:
(i) PV panel without reflector in the horizontal position
(ii) PV panel with reflector in the horizontal position
(iii) PV panel without reflector in the tilted position (30^0 to horizontal)
(iv) PV panel with reflector in the tilted position (30^0 to horizontal)

The readings were taken at four different time period of day. Corresponding irradiance values are provided in Table (3).

Table (3) : Irradiance during different time periods of day

Time	Irradiation (W/m^2)
10.00 AM	536.60
12.00 PM	746.40
2.00 PM	688.00
4.00 PM	408.36

The measured I-V readings were further used to determine the power output, fill factor and conversion efficiency. In order to determine the conversion efficiency, a value of 800 $kJ/m^2/day$ was assumed for average solar irradiance in the prevailing condition **[9]**.

3. Results and Discussions:

3.1 Current-Voltage (I-V) Characteristics:

Figure (3) shows the typical I-V characteristics of solar cell experimental set up under case I conditions (without reflector with PV panel being horizontal) at different periods during the day. It can be seen that current generated remains constant over a wide range of voltage (up to 10-15 V) and then drastically drops down. However, the current generated increased significantly as irradiance of the sun increased, i.e., till 12.00 noon. Thereafter, it decreased and lowest value was recorded at 4.00 PM. Similar behaviors were observed in the other cases (II, III and IV) as well.

When the panel was given an inclination of 30° towards sun's irradiation, a noteworthy increase in the short circuit current was observed (from 0.58 V to 0.66 V). Further, the introduction of reflecting mirrors had significant effect on the short-circuit current (case II and IV). The increase in current was 0.03 A (from 0.58 to 0.61) under horizontal PV panel condition with the introduction of mirror. The corresponding increase under inclined PV panel condition was 0.61 A (from 0.66 to 1.27) as indicated in Figure (4). This can be attributed to the efficient reflecting action of the mirrors in the inclined PV panel position.

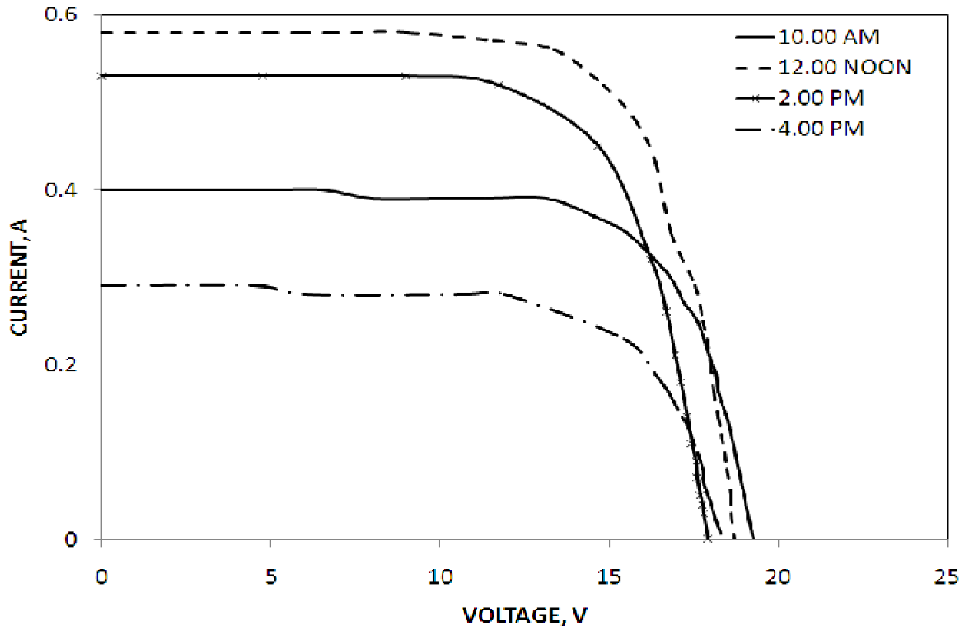

Figure (3): I-V Characteristics of PV panel without reflector on the optimum day with panel in horizontal position

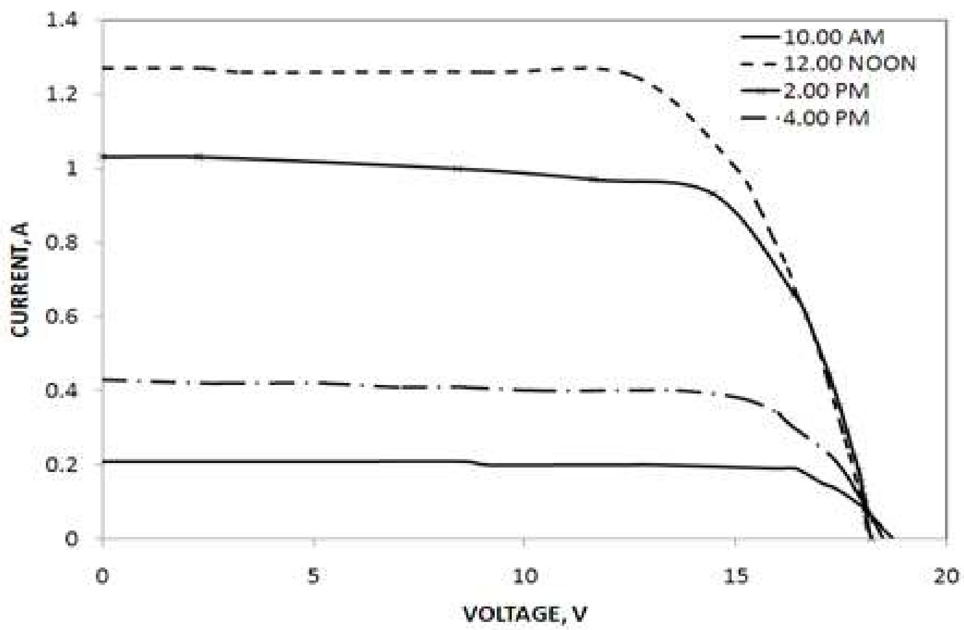

Figure (4): I-V Characteristics of PV panel with reflector on the optimum day with panel at 30° inclination

The data generated was used to estimate fill factor. The fill factor was estimated using the relation:

$$FillFactor = \left[\frac{\operatorname{Im} p * Vmp}{Isc * Voc} \right]$$

The fill factor (FF) of a PV panel is an important performance indicatoralthough physically unrealizable, an ideal PV panel technology would produce a perfectly rectangular I-V curve in which the maximum power point coincided with (Isc, Voc).

The determined fill factors under various conditions were presented in Table (4). As expected fill factors of PV panel at 12.00 noon under different cases were higher than the other situations.However, whenever there was a steep increase in short circuit current (case IV), the fill factor was lower indicating that steep increase in short circuit current may not be useful in improving useful power generation.

3.2 Power and Efficiency:

Figure (5) represents P-V characteristics for Case-I condition. Peak power was highest at 12 .00 noon. Similar behavior was exhibited by the PV panelunder other cases as well. The voltage at peak power and corresponding current values were used to estimate the efficiency of the panel. The calculated values are presented in Table (4). The efficiency values were in the range 8 – 16 % showing specific relation with time period, module position and reflector usage. Significant variations in short circuit current I_{sc} were observed in different time periods, positions of PV module and reflectors. Such changes are responsible for the deviations observed in the efficiency.

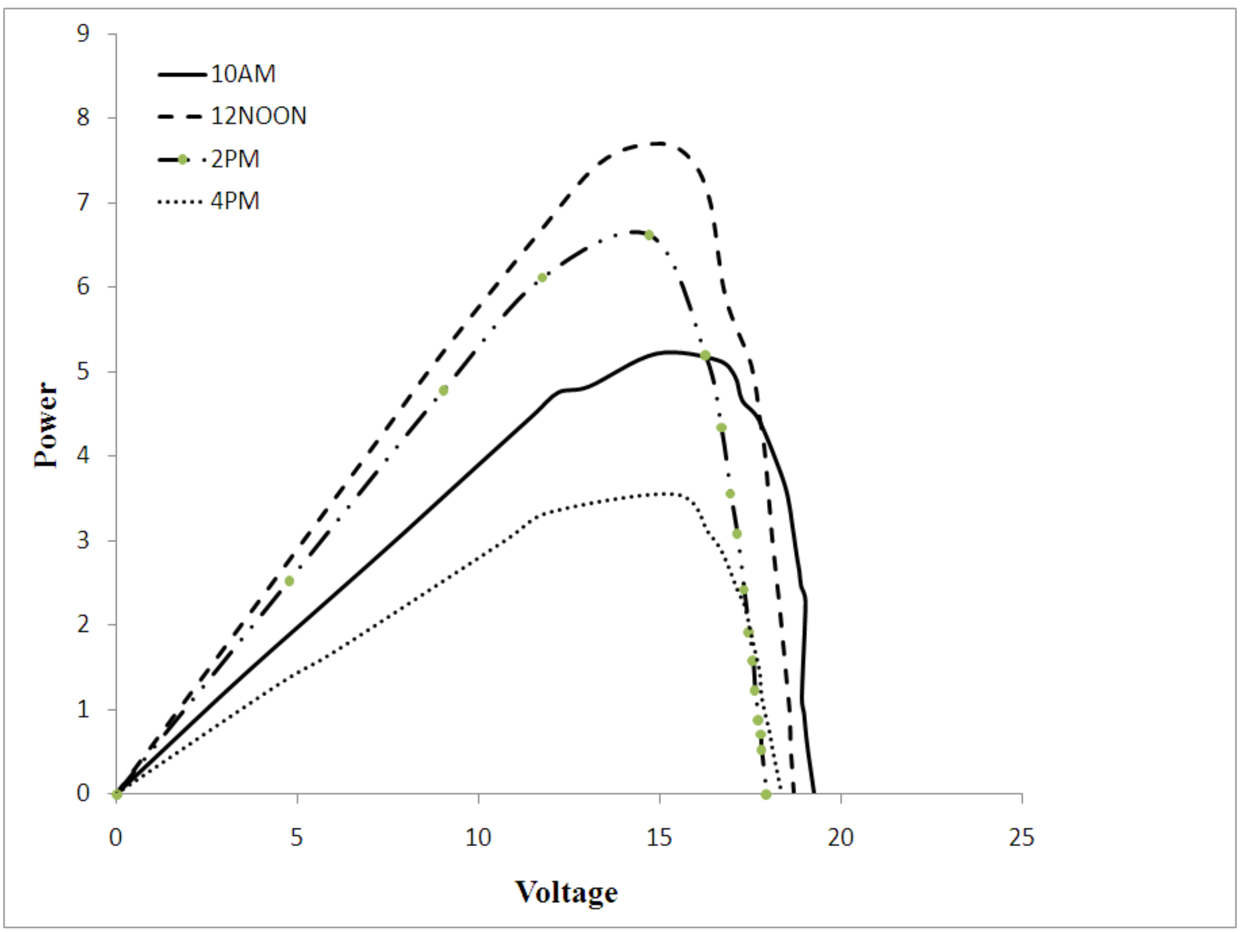

Figure (5) : Power v/s voltage without reflector on the optimum day under case1 condition

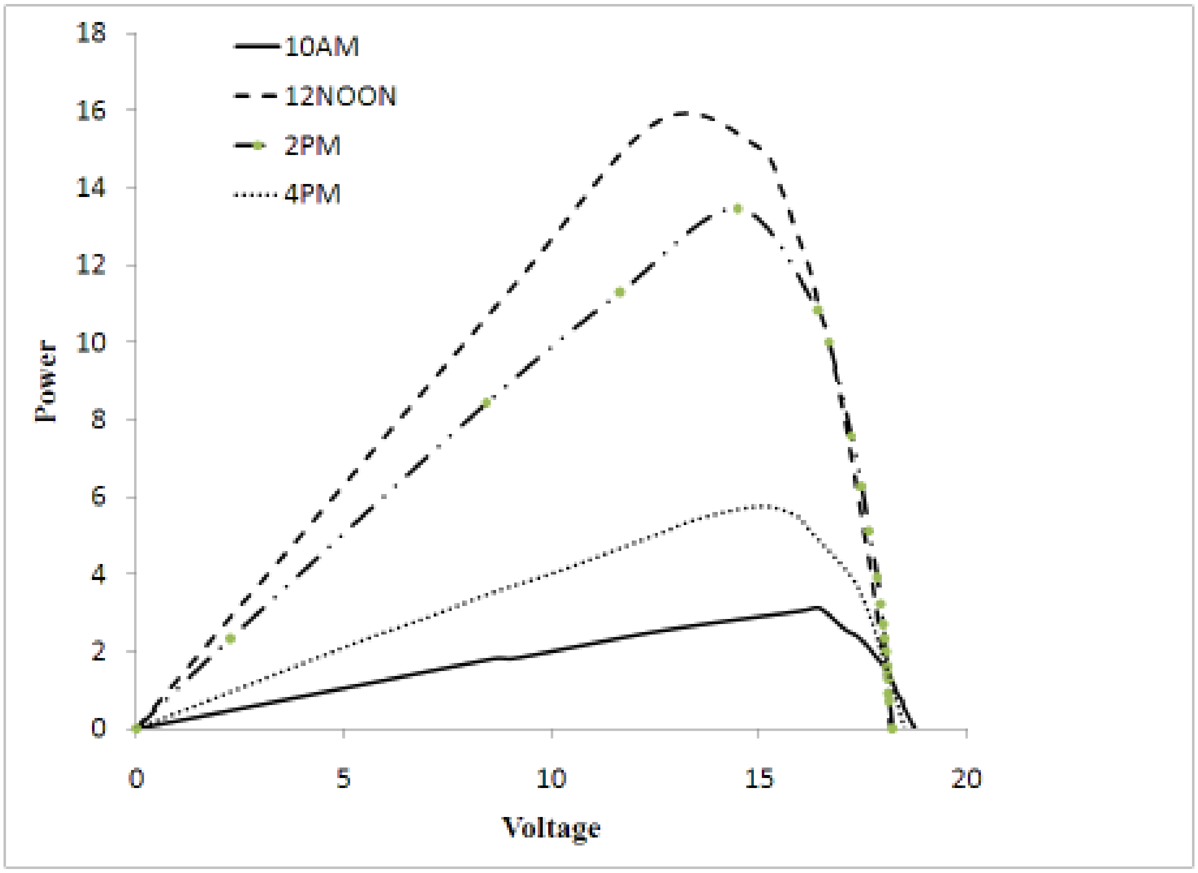

Figure (6): Power v/s voltage withreflector on the optimum day under Case IV condition

Table (4): Fill factor and Conversion efficiency of PV panel.

Case	Description	Time of reading	Fill factor	Conversion Efficiency
I	PV panel without reflector in the horizontal position	10.00 AM	0.704	8.12%
		12.00 PM	0.709	8.27%
		2.00 PM	0.682	6.05%
		4.00 PM	0.666	6.97%
II	PV panel with reflector in the horizontal position	10.00 AM	0.739	10.11%
		12.00 PM	0.749	9.15%
		2.00 PM	0.735	8.91%
		4.00 PM	0.726	8.12%
III	PV panel without reflector in the tilted position (30^0 to horizontal)	10.00 AM	0.712	9.46%
		12.00 PM	0.716	9.53%
		2.00 PM	0.714	10.16%
		4.00 PM	0.703	9.91%
IV	PV panel with reflector in the tilted position (30^0 to horizontal)	10.00 AM	0.793	4.66%
		12.00 PM	0.743	16.5%
		2.00 PM	0.7539	15.7%
		4.00 PM	0.721	11.26%

4. Conclusions:

From the investigations on the effect of reflectors on the performance of PV panel, several conclusions were drawn. An increase of 50 – 60 % in short circuit current was observed with the introduction of reflecting mirrors under horizontal and inclined positions. A corresponding increase in power output was also recorded. The Conversion efficiency seems to be showing slight increase with introduction of reflecting mirrors and inclination of the panel. However, no significant improvement in fill factor values was observed with inclination of the panel and introduction of reflecting mirrors indicating the technique used would be limited use in improving useful power output.

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