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EFFECT OF TRACKING FLAT REFLECTOR USING NOVEL AUXILIARY DRIVE MECHANISM ON THE PERFORMANCE OF STATIONARY PHOTOVOLTAIC MODULE

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ABSTRACT

General ways of cost reduction in solar power generation are Solar Tracked Photovoltaic (PV) arrays and concentrator systems. The PV array tracking becomes infeasible with increase in the size of the array and concentrated system is ineffective for continuous power generation as it requires external cooling system. Proposed approach here is to employ a novel auxiliary mirror drive mechanism to track the sun and reflect the rays on to stationary PV arrays. The performance is compared with same PV module without reflector under the same environmental conditions. Solarex SX 38 PV module and cleardome solar reflector (96% reflectivity) are used for the experiments. PV module is connected to electrical load through Maximum Power Point Tracker (MPPT) and data acquisition system for voltage and current measurements. Incident radiation is measured using Li-Cor pyranometers located on the plane of the module and horizontal plane. A shadow band device is used for the measurement of diffuse solar radiation. The PV module is placed facing south at a tilt angle equal to the latitude angle. A reflector is placed facing north and oriented using the novel Mirror Positioning Device (MPD). The MPD is a five bar spherical mechanism used for solar tracking. This mechanism has two degrees of freedom which allows for tracking the sun along its azimuth and altitude. The mechanism is driven by two servo motors which actuate two links. The actuated link 1 helps in achieving the altitude gained by the sun while the actuated link 2 helps to attain the azimuth (or horizontal movement). The reason for using a spherical mechanism is due to the virtue of its architecture; it allows for carrying a larger payload and also helps in reducing weight. Its advantages are that it requires less power than traditional PV array tracking; there is no need for sensors to determine the position of the sun and also that it being a two degree of freedom spherical mechanism yields a large singularity free mirror orienting workspace. Solar radiation, efficiency, and temperature are plotted as a function of time for analysis. Average diffuse solar radiation is found to be in the range of 15 to 20% of total solar radiation. Different experiments are performed to find out the optimum cycle speed for reflector. Measurements show that output from the PV panel can be increased in the order of 22% with the use of tracking reflector. This work has succeeded in its goal in realization that the considerable increase in output power from PV modules can be achieved.

INTRODUCTION

The current high cost of photovoltaic (PV) system is the major deterrent in its commercialization. Therefore achieving low cost solar electricity is the driving force behind the research and development in photovoltaic technology. Research is in progress in different fields like material, manufacturing process to make photovoltaics cost effective. At the same time study of to improve the total incident solar radiation on the photovoltaic panel is interesting as the output power of the photovoltaic module is directly correlated with the intensity of the solar radiation. Considerable increase in the output of the photovoltaic module can be achieved by increasing the incident solar radiation [1, 2]. Traditional ways of achieving this are solar tracked PV array system and concentrating systems [3, 4].

In solar tracked PV array system, single-axis or two-axis solar tracking mechanisms are used where PV panel is mounted on the device to track the sun. This concept is suitable for single or small number of PV panels but becomes costly with an increase in the number of panels. As the number of the panels increases, the total load requirements will increase which will demand larger actuators and other components of the tracking device. This causes limited use of solar tracking with regard to PV array [5]. Another way of increasing intensity of solar radiation on PV panel is by focusing the solar radiation on it. This will improve the output of the PV panel or reduce the required active material which is expensive. At the same time different issues need to be also considered during focusing of solar radiation on the panel. First, this focusing of solar radiation generates more heat increasing the temperature of the PV module. The efficiency of the conventional PV module decreases with increasing temperature. Therefore passive or active cooling is usually required to keep the temperature of the PV module low [6, 7]. This adds to the cost of the photovoltaic system. Second, concentrating optics are expensive than simple flat plate PV system. Third, solar tracking is required for most of the concentrator systems to be effective. Thus the concentrator system is expensive and ineffective for continuous power generation.

Considering the positive and negative aspects of the above mentioned systems to improve the intensity of the incident solar radiation, a novel alternative to increase the cost effectiveness of PV system has been proposed. The proposed approach is to use a solar tracking device, augmented with a reflector mirror, to continuously track the sun and reflect the solar radiation on to a stationary PV panel [8, 9]. This solar tracking device is referred to as Mirror Positioning Device (MPD). The schematic of the proposed approach is as shown in the Fig. 1.

With the PV panel oriented at latitude angle so as to optimize the intensity of solar radiation [14, 15], the solar tracking reflective mirror will increase the incident solar radiation. The increased solar radiation will thus improve the total output of the PV panel.

The other desired feature of the proposed tracking mechanism is uniform distribution of solar radiation on the surface of the PV panel. Increase in temperature of the panel can also be an issue for this system but uniform distribution of solar radiation avoids concentrating excess solar radiation on solar cell and therefore increase in temperature is considerably less.

The advantages of this approach are the following: The actual load on the tracking mechanism is very less compared to the PV array tracking. The weight of the reflector mirror is much less compared to the PV array. The continuous motion of the reflective mirror to uniformly distribute the solar radiation will avoid concentrating excess solar radiation on solar cell. This will save the solar cells from unfavorable increase in its operating temperature which decreases its efficiency.

The objective of this paper is to compare the output of the PV module with and without the application of MPD. The goal is to perform experimental assessment of the improvement in the output and performance of the photovoltaic module due to application of the MPD.

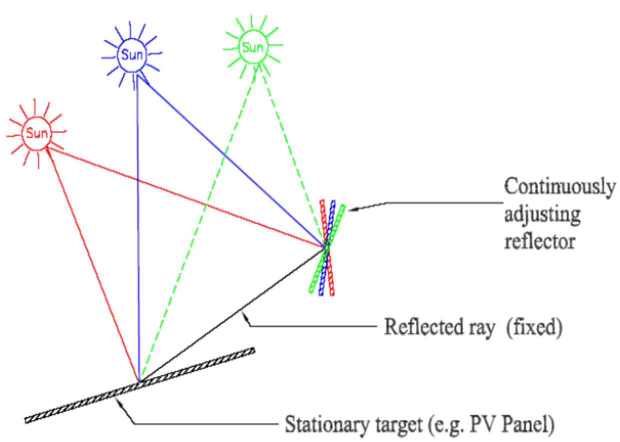

FIG. 1: PROPOSED APPROACH: USE OF MIRROR-POSITIONING DEVICE (MPD).

NOMENCLATURE

I_{sc}	short circuit current (A)
V_{oc}	open circuit voltage (V)
MPP	maximum power point
I_{max}	maximum current (A)
V_{max}	maximum voltage (V)
ff	fill factor
η	Efficiency

EXPERIMENTAL METHODS

The improvement due to application of the MPD is assessed by comparing the improvement in the output of the photovoltaic panel in terms of efficiency. The efficiency of the photovoltaic panel is the ratio of total output power from the photovoltaic panel to the total incident solar radiation on the panel. The parameters used in efficiency calculation are output voltage V in Volts, current I in Amps and incident solar radiation P_o in W/m^2. The efficiency given as

$$\eta = I*V / P_o*A \qquad (1)$$

where A is the area of the panel in m^2. The product of output voltage and current in the above equation gives total output power of the photovoltaic panel. The energy per unit time striking on the photovoltaic panel in the form of solar radiation is measured per unit area and given as P_o. The total incident solar radiation on the panel are calculated considering the area A of the panel. The current and voltage readings are taken at maximum power point (MPP) of the photovoltaic panel.

The experimental arrangement is described below. The photovoltaic panel is positioned east west lengthwise. The panel tilt angle is set to 28^o, which is the local latitude of Melbourne, FL, so as to face in south direction. The panel is connected to the battery through Maximum Power Point Tracker (MPPT). The Mirror Positioning Device (MPD) is fixed so that the reflector will face in north direction. The pyranometrer is arranged to measure horizontal total solar radiation. The shadow ring device is used to measure diffuse solar radiation. Surface temperature of the photovoltaic panel is measured using a thermal imaging camera ((Thermovision 400 Series, AGEMA Infrared Systems). The Labview VI is used to measure the current, voltage, temperature, horizontal solar radiation and the diffuse solar radiation for every 30 seconds interval. For measurement of the parameters without application of the MPD the reflector is taken off the MPD so that no solar radiation is directed on the photovoltaic panel

The photovoltaic panel used for the experiment is polycrystalline solar cell. It is a 38 W photovoltaic panel made up of 36 solar cells. The mirror positioning device has been developed at Florida Tech, which will track the sun with the reflector mounted on it [13]. This tracking mechanism will continuously reflect the solar radiation on the stationary photovoltaic panel throughout the day. Therefore this solar tracking involves accurately determining the position of three bodies viz. sun in the sky, the reflector and the stationary PV arrangement with respect to each other [16]. An algorithm is developed to continuously track the sun for a given longitude and latitude using positional astronomy. The purpose can be achieved using spherical five-bar mechanism. Detailed design is done using Pro-E software and the manufactured parts are assembled to form the desired mirror positioning device. The mechanism is driven by two motors to actuate in two directions viz. the altitude and azimuth. The Cool Muscle motors having inbuilt encoder, drive and controller are used. The motors are controlled via a PC using Cool-Muscle language. Different materials are investigated for solar reflector [17, 18]. Solar reflector with 96% reflectivity as specified by the manufacturer (Clear Dome Solar) is used. This reflector is made by using a patented technique for coating and applying the protective surface. The polycarbonate plastic is used as the substrate. This material has high optical reflectivity, good environmental stability and it is comparatively economical. Ly-Cor pyranometer is used to measure solar radiation.

RESULTS AND DISCUSSION

Before starting to investigate the actual efficiency enhancement due to application of MPD, some preliminary testing of the photovoltaic panel is done to evaluate its basic characteristics. This testing will explain the behavior of the panel under different conditions. I-V Characterization of photovoltaic panel at different incident solar radiation and different temperatures is done to evaluate the behavior of the panel due to these variables. Fig. 2 shows the I-V characteristic of the panel for different incident solar radiation of 200 W/m^2, 500 W/m^2 and 1000 W/m^2 respectively, for a constant temperature of 25^{o}C. It is clear from the Fig. 2 that the I_{sc} and V_{oc} values increase with the increase in the amount of incident solar radiation. Consequently I_{max} and V_{max} also increases, increasing the total output. I_{max} increases considerably with the increase in the incident solar radiation. Value of I_{max} for 1000 W/m^2 is 3.87 times the I_{max} for 200 W/m^2. But the increase in the value of V_{max} is comparatively very small as the V_{max} for 1000 W/m^2 is only 1.05 times the V_{max} for 200 W/m^2. From Table 1 it is evident that the value of V_{max} varies between 12.5 and 13.5 V. It can be better visualized in Fig. 2 that the MPP is in close voltage range. This is helpful in setting the maximum power point tracker.

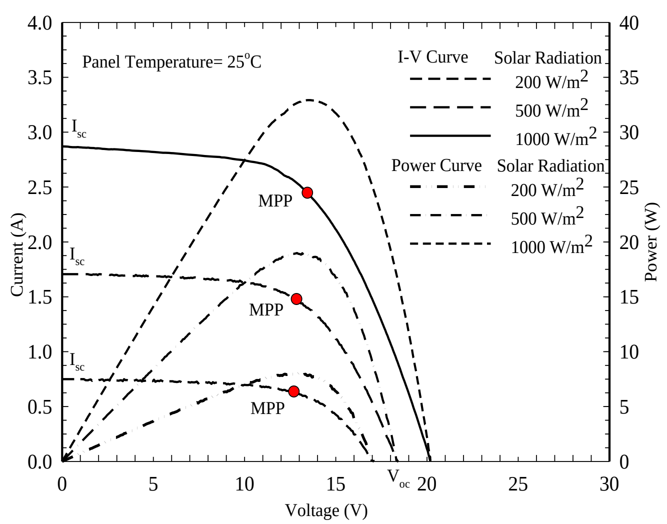

FIG. 2: I-V CURVE AND POWER CURVE OF THE PHOTO-VOLTAIC PANEL AT 25^{O}C PANEL TEMPERATURE AND AT VARYING SOLAR RADIATION.

TABLE 1: PERFORMANCE PARAMETERS OF THE PANEL AT DIFFERENT SOLAR RADIATION FOR CONSTANT PANEL TEMPERATURE.

Radiation (W/m^2)	I_{sc} (A)	I_{max} (A)	V_{oc} (V)	V_{max} (V)	ff	η (%)
200	0.75	0.63	17.09	12.73	62.80	8.05
500	1.71	1.47	18.43	12.87	60.38	8.07
1000	2.87	2.44	20.17	13.47	56.80	8.97

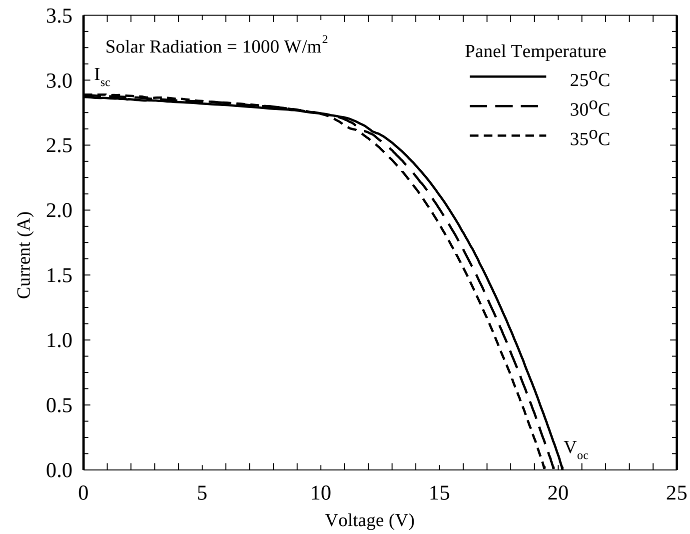

FIG. 3: I-V CHARACTERISTICS OF THE PHOTOVOLTAIC PANEL AT DIFFERENT PANEL TEMPERATURES AND AT 1000 W/ M^2 SOLAR RADIATION.

Fig. 3 shows the I-V characteristics of the panel for incident solar radiation of 1000 W/m^2 with different module temperatures of 25^{o}C, 30^{o}C and 35^o. The performance parameters computed are tabulated in the Table 2. The performance of the panel degrades with the increase in temperature as the efficiency of the panel decreased with the increase in temperature [8, 19]. I_{max} value does not vary much with the variation of the temperature. The difference between I_{max} at 25^{o}C and 35^{o}C is only 0.06A. There is a slight reduction in V_{max} value as the temperature of the panel increases. V_{max} decreased by 0.47V for 10^{o}C rise in panel temperature. Consequently there is slight decrease in the efficiency with the increase in temperature as can be seen in Table 2.

TABLE 2: PERFORMANCE PARAMETERS OF THE PANEL AT DIFFERENT PANEL TEMPERATURES AT CONSTANT SOLAR RADIATION = 1000 W/M^2.

Panel Temp (^{o}C)	I_{sc} (A)	I_{max} (A)	V_{oc} (V)	V_{max} (V)	ff	η (%)
25	2.87	2.44	20.17	13.47	56.80	8.97
30	2.88	2.45	19.80	13.01	56.20	8.88
35	2.89	2.38	19.80	13.00	55.20	8.61

With the application of the reflector on the photovoltaic panel the incident solar radiation on the photovoltaic panel increases. The actual effect is increase in the amount of solar radiation on the panel surface. Consequently temperature of the panel increases with the application of the reflector due to extra solar radiation [19, 20]. Especially in the summer season when the atmosphere is hot and there is no wind for convective cooling and the solar radiation are high, the temperature of the panel itself is very high. Application of reflector further increases the temperature of the panel. From I-V characteristic at different temperatures as presented in Fig. 3, it is evident that with increase in the panel temperature the output and efficiency of the panel decreases. Therefore it is necessary to evaluate if the actual efficiency of the panel increases with application of reflector especially in summer season.

Fig. 4 presents the overall effect of reflector on photovoltaic panel on one of the hot summer day. The solar radiation flux, temperature, current and voltage data is collected from noon to 12:30 p.m. The solar radiation is almost constant at around 850W/m^2 through out the period of data collection and the temperature of photovoltaic panel without reflector is about 60^{o}C. With the introduction of the stationary reflector the temperature starts rising until it reaches the approximate steady-state. With the introduction of reflector, the output power and hence the efficiency of the panel increases. But with the increase in temperature, the efficiency drops until it attains a steady value.

For example with reference to Fig. 4, the average efficiency without reflector is approximately equal to 7.4%. Average efficiency with reflector at steady condition is equal to 7.85%. Therefore, improved efficiency =

$$\frac{(7.85-7.4)}{7.4}\times 100 = 6\%$$

Thus we have attained 6% improvement in the efficiency of the panel due to application of reflector. Therefore the positive effect of increase of solar radiation on the efficiency is more than the negative effect due to increase in panel temperature.

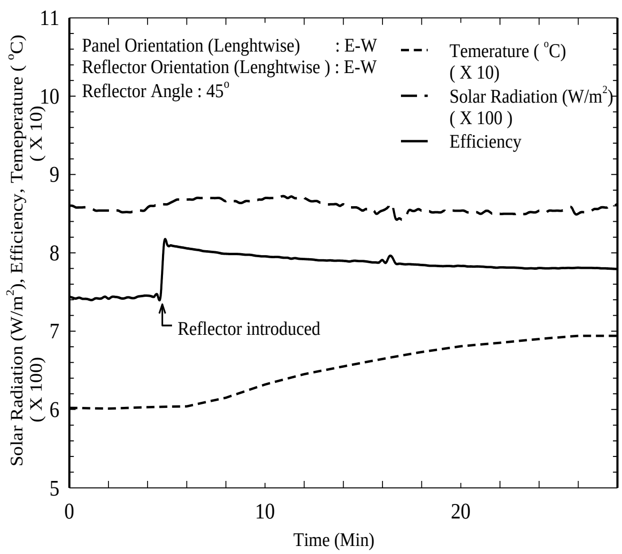

FIG. 4: EFFECT OF STATIONARY REFLECTOR ON THE EFFICIENCY AND TEMPERATURE OF THE PHOTOVOLTAIC PANEL.

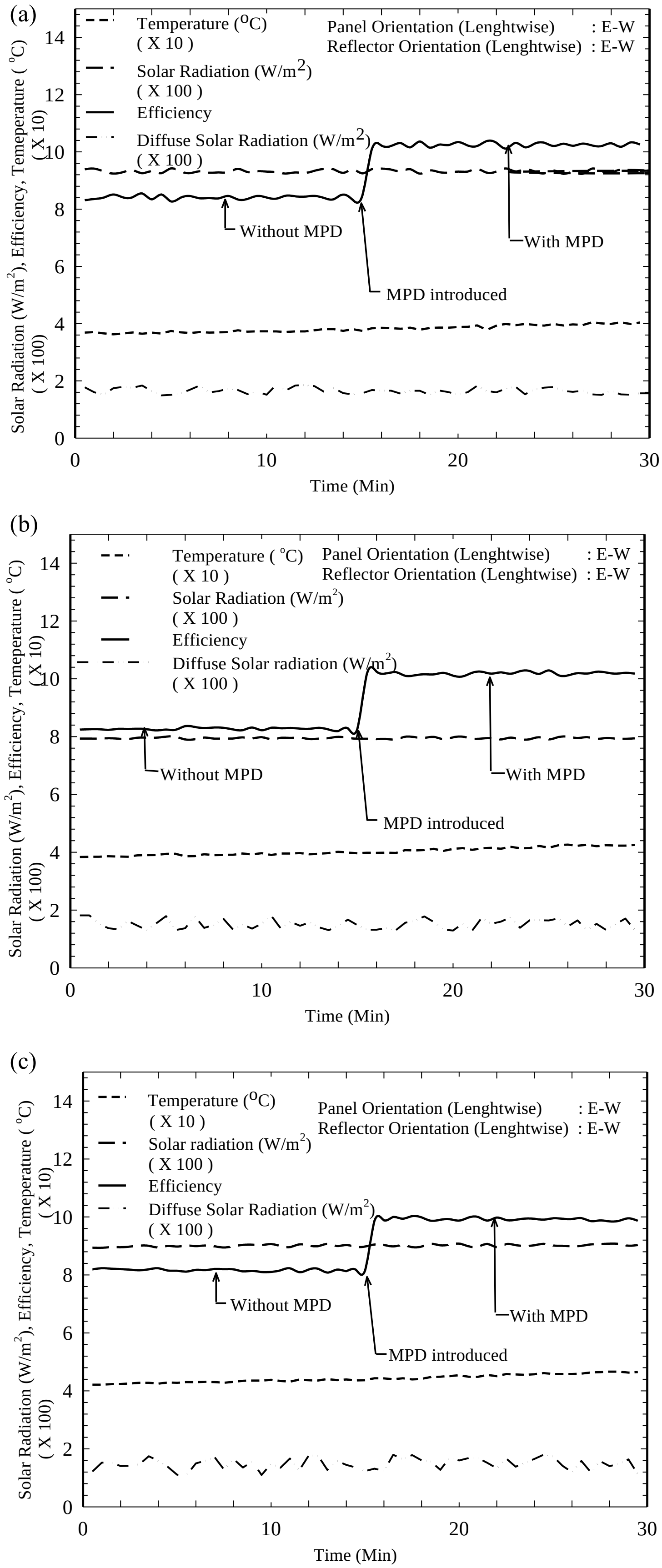

FIG. 5: EFFICIENCY ENHANCEMENT DUE TO APPLICATION OF MIRROR POSITIONING DEVICE FOR DIFFERENT SOLAR RADIATION.

TABLE 3: SUMMARY OF EFFICIENCY IMPROVEMENT DATA DUE TO APPLICATION OF MIRROR POSITIONING DEVICE.

Run No.	Avg. Radiation (W/m^2)	Avg. Diffuse W/m^2)	Diffuse Fraction (%)	Effi. w/o MPD (%)	Effi. with MPD (%)	Improve-ment (%)
1	795	150	18.95	8.27	10.19	23.19
2	931	164	17.68	8.41	10.25	21.82
3	899	148	16.39	8.17	9.92	21.49
				Average Improvement		22.17

After understanding the behavior of the performance parameters of the photovoltaic panel under different conditions, the system final measurement data is taken with the application of Mirror Positioning Device (MPD). Data is collected for three consecutive days, for two hours between 11:00 a.m. and 1:00 p.m. Within the two hour window, 15 minutes steady-state data without application of MPD and 15 minutes steady-state data with application of MPD is plotted in Fig. 5. Fig. 5(a), 5(b) and 5(c) presents the efficiency data of the panel on three different days. The total solar radiation and diffuse solar radiation in W/m^2, temperature of the panel in ^oC, and efficiencies with and without application of MPD are presented in these figures and are plotted against time. The average diffuse radiation is 18% of the total solar radiation. The summary of the collected data is tabulated in the Table 3.

The efficiency improvement calculation for run no.1 is as follows:

Efficiency is calculated using equation (1), where A is the area of the panel in m^2, which is 0.36 m^2. V is output voltage in Volts, I is current in Amps and incident solar radiation P_o in W/m^2. Efficiency of the panel without MPD is 8.27%. Efficiency of the panel with MPD is 10.19%. Therefore,

$$\text{improved efficiency} = \frac{(10.19 - 8.27)}{8.27} \times 100 = 23.19\%$$

Thus we have attained improvement in the efficiency of 23.19 % of the panel is attained with the application of MPD. Similar calculations for other runs give efficiency improvement of 21.82% and 21.49% respectively. Therefore overall average improvement in the output of the panel is about 22% due to implementation of MPD.

CONCLUSION

This paper addresses the improvement in the performance of the photovoltaic system by increasing the total incident solar radiation on the photovoltaic panel using mirror positioning device (MPD). This mirror positioning device continuously reflects the solar radiation on the photovoltaic panel through out the day. This continuously redirected solar radiation increases the total incident radiation on the stationary photovoltaic panel, consequently output power of the photovoltaic panel increases.

Output power of the photovoltaic panel is directly correlated to the intensity of solar radiation. The intensity of the incident solar radiation can be increased by directing extra solar radiation onto the photovoltaic panel by mirror. But the position of the sun changes through out the day. Therefore to achieve optimum reflection throughout the day a novel solar tracking mechanism augmented with a reflector mirror, named as Mirror Positioning Device (MPD) is used. The MPD continuously tracks the sun and reflects solar radiation on the stationary photovoltaic panel. Preliminary testing of the photovoltaic panel is done at a different solar radiation as well as different panel temperatures, so as to obtain guidelines in selecting various parameters during actual testing. It shows that the efficiency of the photovoltaic panel increases with the increase in the incident radiation but decreases with increase in temperature. With application of reflector the total incident solar radiation on the panel increase but at the same time temperature of panel also increases. In order to asses the effect of panel temperature on the output of the panel due to application of reflector, experiments are performed with stationary reflector and panel. The results of these experiments reveal that the output of the panel increases with the application of reflector even at high temperature of the PV panel. The output due to continuous application of reflector is more than switching the reflector on and off the panel. Finally experiments are carried out to evaluate the effect of mirror positioning device on the photovoltaic panel output. These experiments show that the average improvement in the output of the photovoltaic panel is approximately 22% due to application mirror positioning device. This result needs to be verified for the improvement over a complete year. The MPD and photovoltaic panel system have been examined at one latitude only. The percentage of diffuse solar radiation changes with latitude. The percentage of the diffuse solar radiation affects the improvement in the output of the photovoltaic panel due to application of MPD. Therefore this system should be tested at different locations having different latitudes. This paper is one of the first to put forward the concept of MPD to improve the efficiency of PV panels. Additional experiments would have to be conducted to determine if the extra cost and energy usage of the MPD justify its use.

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