Performance improvement of solar PV panel with reflectors and cooling

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***Abstract*—** Due to increase in living standards, there has been an elevation in energy consumption resulting in energy crisis. In the present era, people demand uninterrupted supply of energy and are now focusing on the concept of sustainable development. The major renewable energy source is sun and flat solar panels are mainly used for household demand of energy. But their high cost and low efficiency are the major limitations affecting their commercialization. Reflectors are low cost, simple and effective option for maximizing the output from a solar cell. In this work, calculation of orientation of reflectors is done and a two- reflector system is designed with passive water cooling mechanism so that the temperature increase by reflectors is compensated and an improved output can be obtained.

***Keywords*: Solar Tracker, Concentrator, Reflector, PV, Panel temperature, Orientation**

I. INTRODUCTION

Energy is a fundamental need for human beings in this era. Daily uninterruptable power supply is a necessity for not only the sake of people but also to increase the productivity of a nation. At present, most of our energy requirements are fossil fuel intensive but in recent years, industrial development and population growth resulted in an enormous increase in global demand for energy. The supply of energy has not increased sufficiently to meet the actual demand. The current energy crisis has greatly increased the cost of fossil fuels, and also their reserve will last only for the next few decades. Fossil fuel consumption also causes environmental pollution and degradation. So it is necessary to find alternate energy sources for the future. Energy sector worldwide is now focusing on the concept of sustainable development. Here comes the importance of the renewable forms of energy like solar, wind, wave, biomass, tidal and geothermal energy. Renewable energy sources are intermittent, replenishable, freely available and pollution free. The main source of renewable energy on earth is the sun and electricity is extracted using photoelectric mechanism which makes use of a semiconducting material that converts visible light into a direct current. A series of solar cells are electrically connected to form an array.

A flat solar panel is a practical way in which common households can produce electrical energy. The energy output of these modules is usually very low due to their low power conversion efficiency which is about 15%.The electricity generated depends on the sun intensity and its angle of incidence on the panels. Usually, trackers are used to enhance the power output by physically tracking the panels towards the sun position. Tracked concentrators are also normally used to obtain more radiation. But, all these methods are costly and complex. They have limitations of their own.

The cost of PV modules has been reduced since last few years. Still, it is more expensive than the fossil burned electricity. The significant measures must be undertaken to reduce PV power generation cost by reducing consumption of the cell material. Reflectors placed on the sides of the panel can overcome both these limitations. It reduces PV material consumption since it can avoid the use of another panel by increasing the output. Also, it is a low cost and simple system.

By using PV with reflector technology optical reflectors would replace costly PV cell area by cheaper reflector material such as glass mirror, aluminum sheets, stainless steel, acrylic mirror sheets etc. Reflectors can be positioned at an optimum angle to obtain the maximum amount of sunlight. The technique of using this type of reflectors is a lot simpler and less complicated than the existing concentrators and tracking mechanisms.

II. REFLECTORS

The most inexpensive and effective method to increase the incident solar radiation on the panels is to place reflectors on the sides of the panel so that the diffuse radiation and the radiation falling on the reflectors along its length at different times of the day can be reflected back to the panels which are made use to produce electricity. Reflector is designed to have the same size or larger than the solar panels so that all reflected light falls onto the surface of the solar panel. They can increase the sunlight intensity onto the panel by reflecting sunlight that would normally have missed the panel. The advantages of using planar reflectors are that [1]

1. Irradiance distribution on the receiver will be more uniform compared to curved reflectors.
2. Reduced complexity
3. Zero power consumption of the mirror system
4. Economically viable over sun tracking
5. Installation of mirrors is cheap and simple
6. Does not require any additional complicated equipments or devices

A. Number of reflectors

Using four reflectors on all the sides of the panel can produce a high output, resu1ting in an increase in power output by 1.44% [2]. But, adding more reflectors to a PV system creates a more expensive and complex design structure to the unit. Using 2 reflectors also provide a sufficient increase in the output from a solar cell. A four-reflector module using shiny aluminum produced thrice the peak output power at normal case near the middle of the day when pointed directly at the sun, but cell temperature rose to a very high extent and fractured the glass covering[3] A four-reflector panel would also require full two axis tracking to be effective. For two reflector system outputs will be somewhat less than a four reflector system, but has got some significant advantages.

1. This would allow free flow of air across the panel surface
2. Avoids the cost and complexity of a two-axis mechanism and pedestal for the panel.
3. Allows flush mounting of the panel, on a simple fixed frame or roof.
4. Control over the level of concentration and heat

B. Types of reflectors

The type of reflector panel used influences the output power. Various materials which can be used as reflectors are mirrors, aluminum, stainless steel, chrome film, silver surface and white surfaces. Out of these, chrome film produces an overwhelming increase in the power output. They produce a 27.65% increase in power output than aluminum foil and a 34.05% increase in power output than stainless steel [2]. But, chrome film is costly. When aluminum sheet and stainless steel are compared, aluminum sheet can result in an increase in Isc by 36% when compared to 27.4% increase in Isc in case of stainless steel. Aluminum sheet can be considered as the better option by considering all the electrical parameters as shown in table I [4].

III. DESCRIPTION OF THE SYSTEM

A panel is placed on its support structure tilted at150 to the horizontal facing south in a shadow-free area. The panel performance on a sunny day is noted and analyzed. All electrical parameters namely Voc, Ioc, Vmp, Imp and efficiency are plotted with respect to time. Panel temperature and radiation is also measured with respect to time

Table. I. Solar panel parameters with stainless steel and aluminum reflector

Material Type	Stainless Steel	Aluminium Foil
Imp	21.1%	34.3%
Vmp	0.31%	-2%
Pm	21.5%	31.5%
Isc	27.4%	36%
Voc	0.3%	0.7%
Fill factor	-4.1%	-4.1%

A. Angle between panel and reflectors

Two reflectors will be placed on the east and west sides of the panel so that they can reflect the radiations from the sun as the sun moves from east to west. The dimensions of reflectors are same as that of panel so that all the radiations striking the reflectors will fall on the panel. The angle, reflector should make with the panel to make the radiations falling on the reflectors to reach the panel surface, depends on the position of the sun in sky at different times of a day. It can be calculated using NOAA solar calculator which is a program developed by US government. NOAA gives the direction in which solar radiation falls on the horizontal plane of a particular location at any time of the day of a year. It is called solar elevation angle. This calculator also gives various solar parameters while giving the location, time zone and date as inputs. Here calculations are done based on the location Koovapally (9.5767150^{0}N, 76.83130^{0}E). A panel-reflector system is shown in Fig.1.

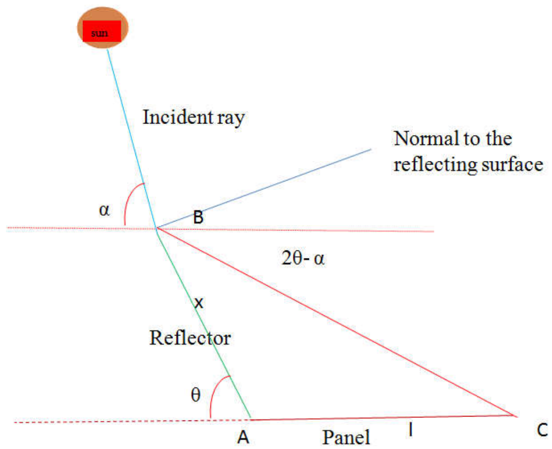

Figure 4.1: Diagram of a panel-reflector system

x = length of diffused reflector
l = length of solar panel
θ= the angle the reflector makes with the horizontal plane

From ABC,

$$\frac{l}{\sin(\alpha-\theta)} - \frac{x}{\sin(2\theta-\alpha)} \qquad (1)$$

$$\frac{l\sin(2\vartheta-\alpha)}{\sin(\alpha-\theta)} = x \qquad (2)$$

When reflector dimensions are same as panel

$$(\sin(\alpha-\theta) = (\sin(2\theta-\alpha) \qquad (3)$$

Solving eqn.4.3, value of θ can be calculated. After reflectors are fixed, the performance of panel will be analyzed when aluminum sheet is used as reflector.

B. Panel specifications

A 60W panel is tested in this work. The specifications of the panel are as follows:

Dimension: 740 x 675 x 35 mm
I_{sc} = 3.836 A
V_{oc} = 21.9 V
I_{mp} = 3.59 A
V_{mp} = 17.7 A
η = 12.69%

C. Calculation of reflector orientation

D. Experiment and results

The experiment is done by placing two aluminum sheet reflectors on either sides of the panel. The panel is tilted 15^0 to the south.

Time	Angle of elevation	Reflector angle
9:00:00	40.344	26.89
9:30:00	47.21	31.47
10:00:00	53.98	35.98
10:30:00	60.58	40.39
11:00:00	66.85	44.56
11:30:00	72.41	48.27
12:00:00	76.36	50.9
12:30:00	77.1	51.4
13:00:00	74.94	49.4
13:30:00	69.09	46.06
14:00:00	63.03	42.02
14:30:00	56.53	37.69
15:00:00	49.81	33.21
15:30:00	42.98	28.65
16:00:00.	36.08	24.05
16:30:00	29.15	19.43
17:00:00	22.21	14.81

Table II. Solar radiation incident angle and reflector angle for different times of June 10th, 2015

The angle at which the reflectors should be placed with the panel are found using angle of elevation. Angle of elevation is calculated using NOAA solar calculator. Using eqn.(3), orientation of reflectors so that the radiation falling on the topmost point of the reflector strikes at the edge of the panel can be calculated. Table II and Table III shows the angle of elevation and corresponding value of θ for the days June 9th and 10th of 2015. When θ is varied, different orientations for making the radiation to fall inside the panel are obtained.

By analyzing tables II and III, it is observed that the reflector orientation and angle of elevation at the same time of different days are almost same. They vary by a maximum of only 1^0. So, it is inferred that there is no need for adjusting the reflector angle daily.

Table III. Solar radiation incident angle and reflector angle for different times of June 9th, 2015

Time	Angle of elevation	Reflector angle
9:00:00	40.02	26.68
9:30:00	46.85	31.23
10:00:00	53.57	35.71
10:30:00	60.12	40.08
11:00:00	66.32	44.21
11:30:00	71.79	47.86
12:00:00	75.68	50.45
12:30:00	76.52	51.01
13:00:00	73.83	49.2
13:30:00	68.93	45.95
14:00:00	62.99	41.99
14:30:00	56.58	37.7
15:00:00	49.92	33.2
15:30:00	43.13	28.7
16:00:00	36.28	24.1
16:30:00	29.38	19.59
17:00:00	22.48	14.98

Using trial and error method an angle θ which fits the eqn.(2) such that radiation falling on the reflector could strike the surface of the panel is found out and its value is 120^0. That is, the interior angle between the panel and reflector is 60^0.

Time	Panel Temp.	P_{max}	Radiation	Efficiency
10	38.1	34.24	875.4	7.82
10.15	40.03	38.55	875.9	8.8
10.3	43.47	40.58	902.4	8.9
10.45	45.79	35.50	909.03	7.8
11	47.81	44.38	894.70	9.9
11.15	50.26	48.96	954.91	10.2
11.3	52.12	26.79	986.77	5.42
11.45	53.85	33.02	1003.91	6.5
12	50.09	35.36	1059	6.6
12.15	52.47	46.98	972.69	9.6
12.3	53.29	42.94	973.30	8.8
12.45	54.7	46.086	1002.69	9.1
1	56.76	34.65	1010.03	6.8
1.15	58.27	52.59	994.12	10.56
1.3	59.27	45.01	942.70	9.5
1.45	55.39	49.01	959.84	10.2
2	54.28	49.45	930.45	10.6

Table IV. Solar PV parameters using PV panel only on 9^{th}, June 2015

The reflectors will be facing east and west directions. Till 12.15 PM, only the reflector facing east direction will be used and after that only the west facing reflector will be used. Experiments are done on June 9^{th} and 10^{th}, 2015 and the following results are obtained.

Time	Panel Temp.	P_{max}	Radiation	Efficiency
10	42.48	38.04	905.18	8.4
10.15	43.69	41.85	905.75	9.24
10.3	47.33	43.11	933.09	9.24
10.45	48.55	46.92	939.93	9.98
11	52.80	45.65	925.12	9.87
11.15	57.05	44.38	987.37	8.9
11.3	60.4	51.36	1048.92	9.7
11.45	63.11	53.88	1067.14	10.1
12	60.69	57.06	1125.7	10.1
12.15	59.29	54.5	1033.9	10.5
12.3	60.3	51.99	1034.6	10.053
12.45	62.31	46.9	1065.84	8.8
1	63.31	45.6	1073.65	8.5
1.15	61.90	41.87	1056.73	7.9
1.3	62.31	40.5	992.9	8.1
1.45	63.31	46.92	1011.01	9.28
2	59.2	45.65	980.06	9.3

Table V. Solar PV parameters using reflectors on 9^{th}, June 2015

Table IV shows the panel parameters without reflectors on 9th June, 2015. Table V shows the same parameters while using reflectors on the same day. While comparing the two tables, it is seen that the radiation falling on the panel with reflectors is higher. In that case, maximum power produced is also high. It implies that when radiations falling on a panel increases, output power also increases correspondingly. Similarly, tables VI and VII show the parameters with and without reflectors on June 10th, 2015. The same effect as on the previous day is observed here also in case of radiation and maximum power produced. While analyzing the values of efficiency and panel temperature, it is observed that the panel temperature increases than a normal range when more radiations strike it and correspondingly the efficiency of panels reduce. Though the power produced increases, the conversion efficiency of the

Table VI. Solar PV parameters using PV panel only on 10th, June 2015

Time	Panel Temp.	P_{max}	Radiation	Efficiency
10	37.03	33.21	857.91	7.74
10.15	38.83	37.39	858.45	8.71
10.3	42.17	39.36	884.37	8.9
10.45	44.42	34.44	890.85	7.73
11	46.37	43.05	876.81	9.82
11.15	48.75	47.49	935.81	10.15
11.3	50.56	25.98	967.04	5.3
11.45	52.2	32.03	983.83	6.51
12	48.59	34.3	1037.82	6.61
12.15	50.89	45.57	953.24	9.5
12.3	51.69	41.66	953.84	8.73
12.45	53.09	44.70	982.63	9.09
1	55.06	33.61	989.83	6.79
1.15	56.52	51.01	974.23	10.4
1.3	57.49	43.66	923.84	9.45
1.45	53.73	47.54	940.64	10.10
2	52.65	47.97	911.84	10.52

Table VII. Solar PV parameters using reflectors on 10th, June 2015

Time	Panel Temp.	P_{max}	Radiation	Efficiency
10	41.2	36.90	887.07	8.3
10.15	42.38	40.59	887.63	9.1
10.3	45.91	41.82	914.4	9.14
10.45	47.09	45.51	921.1	9.88
11	51.2	44.28	906	9.76
11.15	55.33	43.05	967.6	8.8
11.3	58.6	49.82	1027.9	9.6
11.45	61.2	52.28	1045.8	9.98
12	58.8	55.35	1103	10.03
12.15	57.5	52.8	1013.27	10.4
12.3	58.4	50.43	1013.9	9.94
12.45	60.4	45.5	1044.5	8.71
1	61.4	44.2	1052.17	8.41
1.15	60.04	40.59	1035.5	7.83
1.3	60.44	39.36	973.10	8.09
1.45	61.41	45.51	990.79	9.18
2	57.51	44.28	960.46	9.22

effect on the performance of solar panels. Conducting materials make use of free electrons whereas some electrons are tightly bound to the nucleus of atom. As solar radiation increases, more photons strike the panel. This energy is absorbed by the stationary electrons and they get released by breaking the bond. Thus, they move freely and collide with each other emitting more electrons from the atoms resulting in an increase in temperature. Increase in temperature causes increase in resistance to the flow of current [6]. All electrical parameters of solar cell such as maximum output power, open circuit voltage, short circuit current, and fill factor get affected with temperature variation. So, reflector system should always include a cooling mechanism. In this work, passive water cooling is used. Since a passive cooling technique is used, the power consumption is negligible and a low cost system can be designed.

III. COOLING SYSTEM

An absorber plate made of Aluminium sheet is provided at the bottom of the panel. Copper tubes are braced to the absorber plate which carries water. Glass wool is provided over the tubes for insulation. 2 storage tanks are provided to store cold and hot water. Heat exchange occurs through natural convection. Table VIII and IX shows the panel parameters without reflectors and with reflectors and cooling respectively on 11th June, 2015

Table VIII. Solar PV parameters using PV panel only on 11th, June 2015

Time	Panel Temp.	P_{max}	Radiation	Efficiency
10	29.62	33.2	886.1925	7.495865
10.15	31.06	36.5	886.7502	8.240266
10.3	33.73	37.6	913.52	8.24118
10.45	34.53	40.9	920.2125	8.903119
11	36.10	39.8	905.7122	8.801179
11.15	37.004	38.7	966.6569	8.017229
11.3	39.45	44.8	1026.918	8.732689
11.45	40.78	47.05	1044.755	9.007475
12	40.87	49.84	1102.089	9.041165
12.15	41.71	47.608	1012.266	9.405948
12.3	41.35	45.3	1012.903	8.962821
12.45	41.47	40.9	1043.481	8.10748
1	43.04	39.8	1051.125	7.884883
1.15	43.28	36.53	1034.562	7.062946
1.3	42.99	35.4	972.1317	7.288756
1.45	42.97	40.91	989.8068	8.277131
2	42.94	39.85	959.5066	8.307744

Time	Panel Temp.	P_{max}	Radiation	Efficiency
10	32.96	26.57	708.954	7.495865
10.15	33.9	29.91	640	9.349097
10.3	36.7	31.49	730.816	8.618228
10.45	37.6	27.55	736.17	7.486106
11	40.9	34.44	724.5697	9.507447
11.15	44.27	37.99	773.3255	9.826832
11.3	46.9	20.78	821.5341	5.061126
11.45	48.9	25.62	835.8039	6.132148
12	47.0	27.44	881.6712	6.225679
12.15	46.01	36.46	809.8125	9.005405
12.3	46.7	33.32	810.3221	8.226121
12.45	48.35	35.76	834.7846	8.568139
1	49.13	26.89	840.9003	6.396456
1.15	48.03	28	827.6497	6.766147
1.3	48.35	30	777.7054	7.715004
1.45	49.13	28	791.8455	7.072087
2	46.01	29.54	767.6053	7.696664

Table IX. Solar PV parameters using reflectors and cooling on 11th, June 2015

By analyzing the tables VIII and IX, it is observed that when cooling is provided, the conversion efficiency of the panel is increased. The temperature of the panel is not exceeding a safe limit and thus, the panel performance is not affected. Also, since reflectors are there, more radiations strike the panel and output power is increased.

IV. CONCLUSION

Use of reflectors with passive cooling technique is a low-cost and simple method to improve the efficiency and output power of a panel. A significant increase in efficiency and power output is observed. By giving cooling, temperature of the panel is reduced by about 10^0 C. Also, if the water used for cooling is collected in a proper way, it can be consumed and this method can be used as an alternate form of water heating during summer season.

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