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Efficiency Improvement of a Typical Solar Panel with the Use of Reflectors

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ABSTRACT

A cost effective alternative technique to increase the efficiency of photovoltaics is introduced. The design is fabricated and validated through field testing. The output of a smaller scale solar panel is measured with different reflector materials. Further the reflectors are strategically placed in a way that it would help cool down the solar cells with the use of natural air flow. Temperature of the solar cell is also recorded at different wind speeds and with each different reflector and is compared with each other. According to the results aluminium coated paper is found to be the best option for reflector material. In compensation with the durability and performance, the conventional mirrors are identified as the ideal option and further analysis is done based on the same. The payback period analysis is conducted between a conventional design and the proposed design and it is found that the proposed design gives a considerably short payback period and a strong price to performance ratio.

Key words: photovoltaics, reflectors

INTRODUCTION

Solar power market had a rapid expansion in the recent years mainly due to the plummeting prices of solar PV panels [2]. But most of the PV panels only convert less than 20% of the sunlight in to electricity. Although multi junction concentration PV systems that has efficiencies as high as 40% exists the cost of production still makes them out of reach for small businesses and homes [3]. There has been numerous research papers published on the subject of increasing the efficiency of a solar panel. Notably in the paper, More efficient use of photovoltaic solar panel using multiple fixed directed mirrors or aluminium foils instead of solar trackers in rural perspective of Bangladesh [4] [11] [12] set out to find if the output of the PV panels increase with the use of reflectors. But focusing sunlight on to the small area via reflectors tends to cause other problems with the sun tracker system. And the focused sunlight might also cause the PV panel temperature to elevate. In the paper Photo voltaic cell efficiency at elevated temperatures [5] [9] [14] discusses about the importance of keeping the temperature of a photo voltaic panel to ensure that the photo voltaic cells operates at the optimum conditions. The paper finds that higher temperature might even permanently damage the solar cells. The final design will have to address all these issues.

The aim of this paper is to find the best value for the money by implementing the most suitable method of solar power installation. Since solar power installation is already a significant investment, designing a system that uses the most out of a conventional photo voltaic panel array by keeping them at their peak efficiency for as long as possible was essential. Several methods are proposed and tested in this project that will allow the PV panel to work at optimum conditions for a longer period of time [8]. The investigation was more focused on developing a design that harnesses the power of wind to passively cool down the PV panels. The output power and the PV panel temperature was recorded at different wind speeds and was finally compared to find out its effectiveness.

METHODOLOGY

The sunlight hitting on the surface of the solar panel can be intensified by the use of parabolic shaped reflectors and flat panel reflectors [7]. Since the manufacturing cost of curved reflectors are higher than that of flat panel reflectors [6] the methods proposed in this section will utilize the use of flat panel reflectors. And since the solar intensifier only works at a certain spot in a certain direction the solar panels and the reflectors are in need of a solar tracker system. Although implementing such a system to focus the sunlight on to a smaller area will cause a rise in the temperature and a separate cooling system will also be needed. The concept will utilize two mirrors which will be at fixed angles and they each would reflect additional sunlight on to a half of the solar PV panel. The cooling will be done by a passive air cooling method. As illustrated in the Fig. 1 mirrors will be fixed on to the frame leaving a small gap between the solar panel and itself. By adding some wind deflectors on each side the whole structure will act as a giant funnel to direct the naturally flowing wind in to the air gap thus cooling down the solar panel.

Although Sri Lanka being a country that is very close to the equator and the path of the sun does not get very far off to north or south as much as in northern or southern countries, having two separate automated tracking mechanisms to track the sun in both axis would dramatically increase the payback period of the whole system. Therefore the concept 3 will have a single automated axis sun tracking mechanism to track the sun west to east, and a manual (human operated) tracker to change the north-south angle every couple of weeks.

The mechanism for the manual adjustment of the solar PV panel (north-south wise) uses a threaded shaft and a nut that runs along with it. When the thread shaft is rotated by the handle the nut will run along the thread bar, raising the arm that supports the PV assembly.

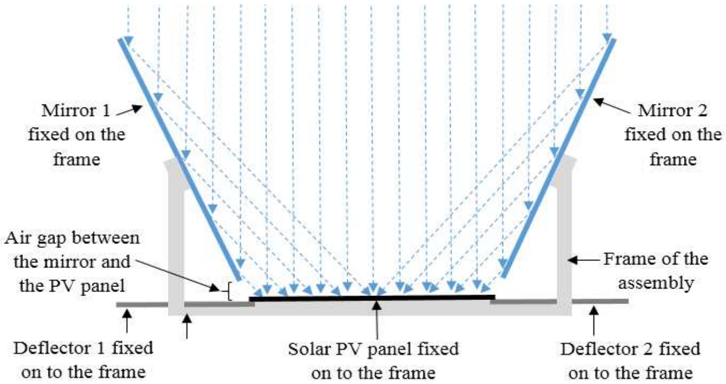

Fig. 1 Design of the concept 3. This design exercises the fact that the client company is situated in a location where wind resources are plenty

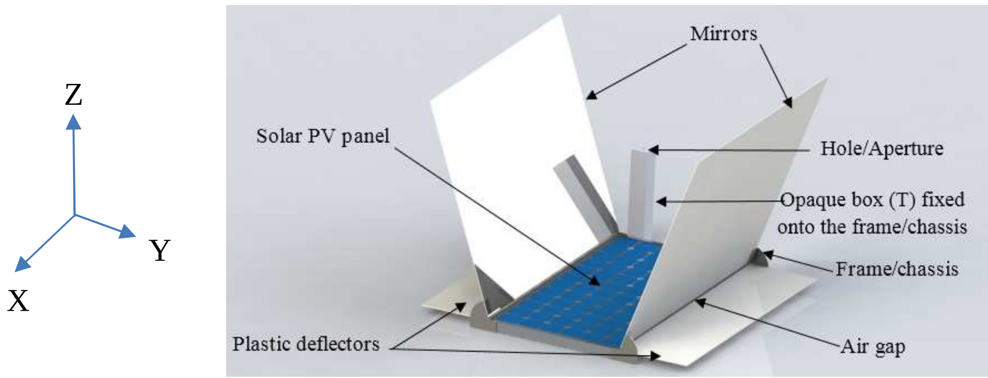

Fig. 2 A 3-D rendering of the mirror, PV panel and the deflector assembly

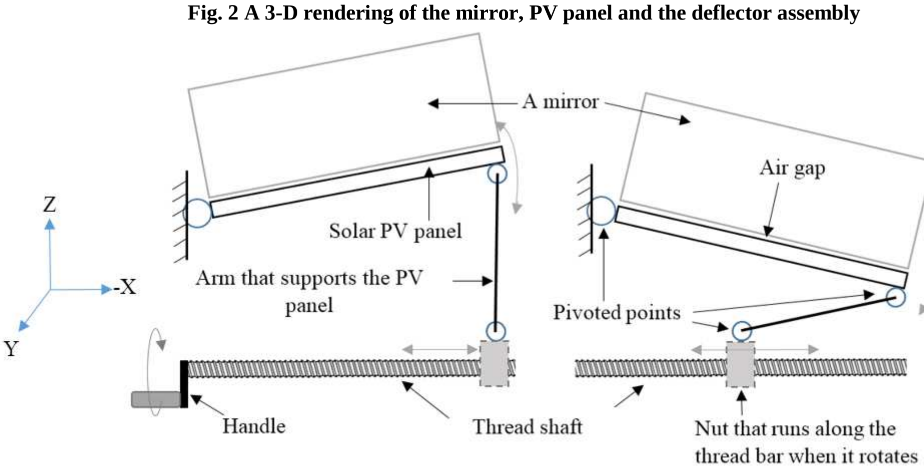

Fig. 3 A side view of the solar panel assembly mounted on a threaded shaft

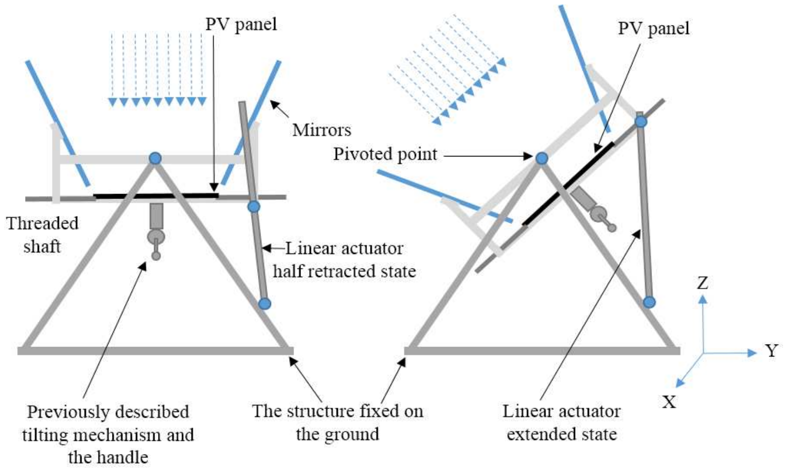

Fig. 4 The mechanism that pivots the assembly (PV panel, mirrors and the deflectors) which is controlled by a linear actuator, the front view

The handle is only meant to turn once every couple of weeks as the angle of the sun rise gradually changes over the seasons in a calendar year. This unique design will allow an array of solar panels to be connected together and they all will be turned by a single thread shaft and a motor. The whole assembly will be pivoted as the sun moves from east to west during the day with the use of a linear motor. The PV panel, mirrors and the wind deflector assembly is pivoted through its centre of mass reducing the torque required to pivot the assembly.

ANALYSIS

The solar PV panel that will be subjected for the calculations is IBC PolySol 250 GX. The basic dimensions are $1654 \text{ mm} \times 989 \text{ mm} \times 40 \text{ mm}$. The panels are made out of polycrystalline solar cells which have and efficiency of 15.6%. [15] [10].

The first step of the design is to add the mirrors to focus additional sunlight on to the solar panel. In this design two mirrors will be used, each reflecting sunlight on to a half of the PV panel. The original area that the sunlight can be collected is only $1654\text{mm} \times 989\text{mm}$. Following are the diagram illustrates the utilisation of the mirrors to maximise the solar panel output at a mirror angle of θ^0. Following are the calculations carried out to find the angles between the PV panel and the mirror and the required length of the mirror, and to select the best angle, considering the cost of the mirror and additional effective width that the mirror creates. The sunlight hitting the additional effective area will be reflected on to a half of the PV panel (other half will be covered by the mirror on the opposite side).

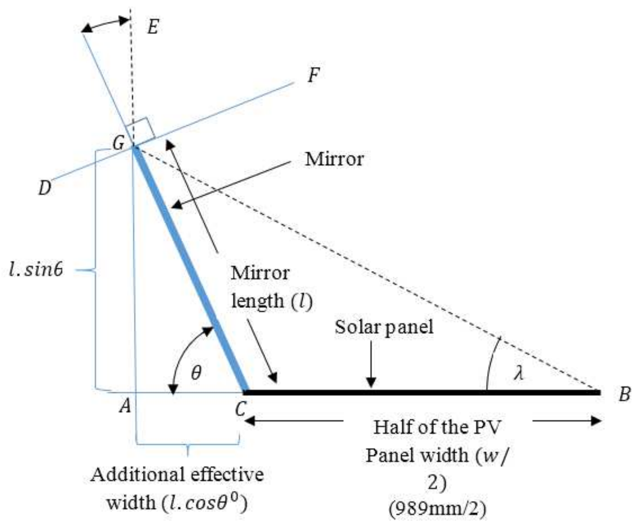

Fig. 5 Illustration for the geometrical calculation

Since $A\hat{C}G = \theta$, $D\hat{G}C = 90^0$, $D\hat{G}A = \theta$

since $D\hat{G}A$ and $E\hat{G}F$ are opposing angles

$E\hat{G}F = \theta$

since $E\hat{G}F$ and $F\hat{G}B$ are angles of the reflecting sunrays they also have to be euqal

therefore $F\hat{G}B = \theta$

$F\hat{G}B + B\hat{G}C = 90$

$B\hat{G}C = 90 - \theta$

Considering the triangle of CGB;

$B\hat{G}C + GCB + CBG = 180^0$

since $B\hat{G}C = (90^0 - \theta)$, and $GCB = (180^0 - \theta)$

$(90^0 - \theta) + (180^0 - \theta) + CBG = 180^0$

$CBG = \lambda = 2\theta - 90^0$

And using the law of sins for the same triangle

$$\frac{\text{mirror length (l)}}{\sin(2\theta - 90^0)} \frac{\text{half of the PV panel width } \left(\frac{w}{2}\right)}{\text{Sin}(90^0 - \theta)}$$

$$\frac{\text{mirror length (l)}}{-\cos(2\theta)} = \frac{w}{2\cos\theta}$$

$$\text{mirror length (l)} = \frac{-w\cos(2\theta)}{2\cos\theta}$$

Notice that the θ always has to be between 45 and 90 degrees for the last equation to be true. By applying various values for θ the following table can be created. The width of the mirror which is equal to the length of the solar panel which is 1654mm. The area of the mirror is calculated by multiplying (l)mm by the length of the solar panel (1654mm) and the effective area of the mirror is calculated by multiplying additional effective width (x) mm by 1650mm.

With that information following graph can be plotted with the cost values against the additional area that the mirrors provide. The cost threshold has selected to be $4 for this application. And the corresponding θ value that is closest is 70^0 degrees and the length of the solar panel is 1119.88mm. The design will be carried forward with these values.

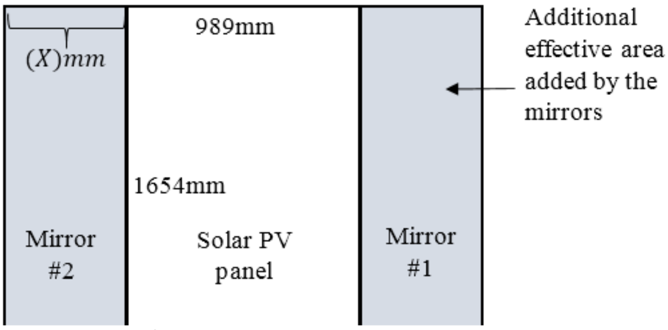

Fig. 6 Top view of the solar panel mirror assembly

Table -2 Calculation to Find the Effective Area of the Mirrors

θ^0	l(mm)	Additional effective width achieved through the use of mirrors (x)= $lcos\theta$ (mm)	Additional effective area (m^2) $lcos\theta \times 1.654$	Cost with the average price of US $2.128 per square metre
45	0	0	0	-
50	135.074	86.82	0.143	0.475
55	298.146	170.92	0.281	1.049
60	500.000	250.00	0.413	1.75
65	760.482	321.18	0.530	2.67
70	1119.88	383.02	0.633	3.94
75	1673.03	433.01	0.716	5.88
80	2705.73	469.84	0.775	9.52
90	∞	-	-	-

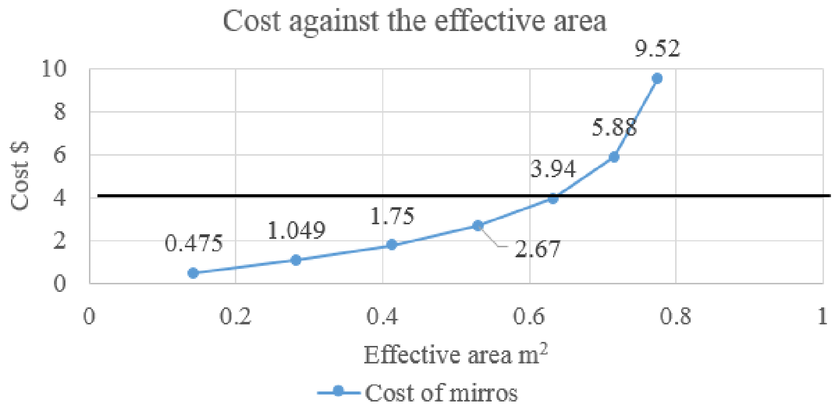

Fig. 7 The cost of mirrors plotted against their effective area, the selected cost threshold has been marked at $4

Following are the calculations for the mechanism to adjust the tilt of the solar panel. Since the sun rises at different angles year around, due to the tilt of earth's rotational axis, the angle of the solar also has to change year around. The tilt in the earth's rotational axis is 23.5 degrees [16] and that causes the path that the sun travels vary by 23.5 degrees to the north and 23.5 degrees to the south throughout the year. In this mechanism this angle variation is achieved through the following design. The arm will control the tilt of the PV panel. Rotating the thread shaft will therefore tilt the PV panel to a desired tilting angle. Since this mechanism is being developed in Sri Lanka the angles have to be set according to the geological location of Sri Lanka. Being situated at latitude of 7 degrees north would mean the variation of the rising angle of the sun will be 7 degrees off from the centre. This is illustrated in the Fig. 9.

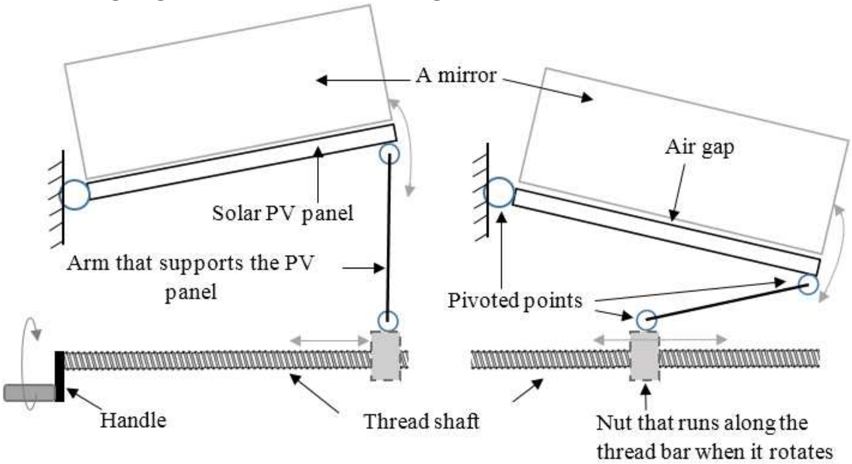

Fig. 8 An illustration of the different tilt positions of the same solar panel

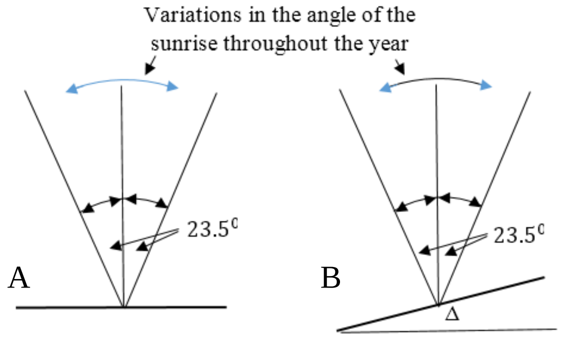

Fig. 9 Variations of the angles of sunrise throughout the year, Country on the equator (A) versus a country in the latitude of Δ, (B)

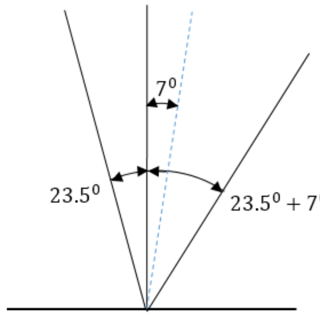

Fig. 10 Illustration of the variation of the angle of the sunlight observed from a latitude of 7 degrees throughout the year

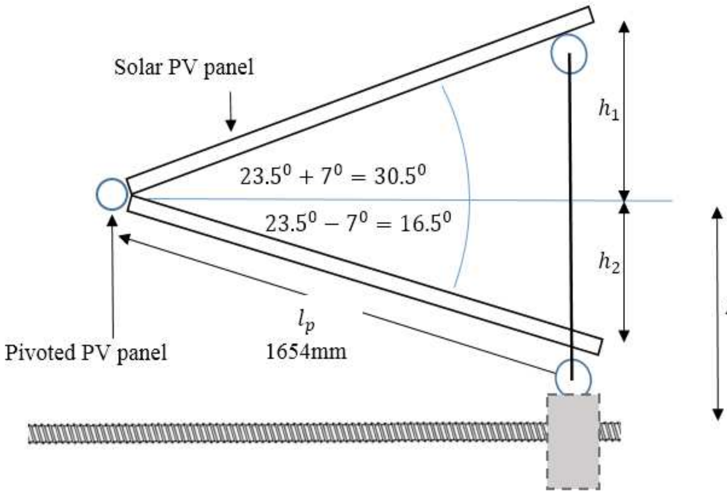

Fig. 11 The dimensions of the mechanism that tilts the PV panel. The mechanical arm that connects the threaded nut that runs along the thread bar to the PV panel

Since Sri Lanka is situated at latitude of 7 degrees the azimuth angles that are required for the mechanism would be as shown in Fig. 10. Therefore the dimension in the parts of the tilting mechanism has to be as follows.

$$h_1 = 1654\text{mm} \times \sin 30.5 = 839.5\text{mm},\ h_2 = 1654\text{mm} \times \sin 16.5 = 469.8\text{mm}$$

H = the gap between the pivoted PV panel end and the threaded shaft. This includes the h_2 value plus the height of pivoted nut at minimum. This gap has to be higher than h_2 or the PV panel will collide with the thread shaft at certain angles. Length of the mechanical arm has to exceed $h_1 + h_2$ minus the height of the nut that runs along the threaded shaft.

$$\text{length of the mechanical arm} = 839.5\text{mm} + 469.8\text{mm} + \sim 10\text{mm} = 1319\text{mm}$$

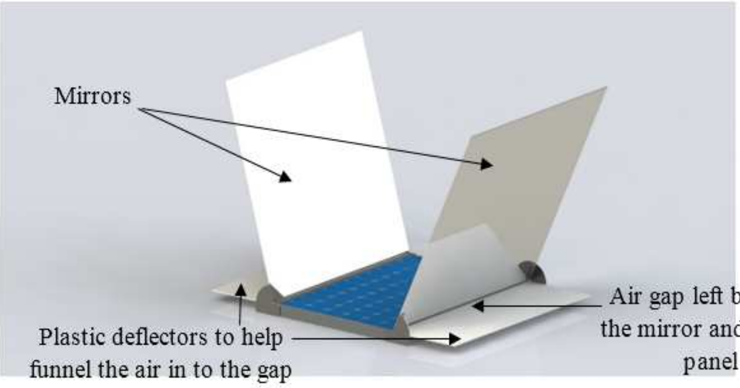

Fig. 12 A rendered model of the proposed design

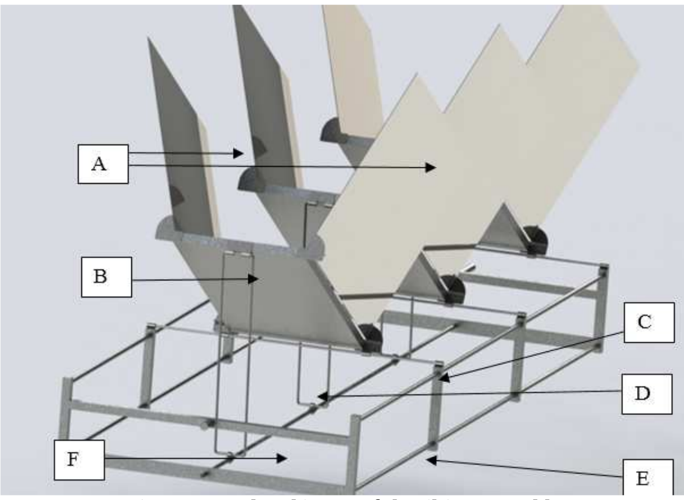

Fig. 13 A rendered image of the tilting assembly

A = Mirrors on either side of the PV panel
B = Bottom side of the PV panel
C = Screw thread that tilts the PV panel
D = The mechanical arm that links the nut (F) to the solar panel.
E = The railing frame that holds the whole assembly together.
F = Nut that is linked to the mechanical arm and runs along the screw shaft when the screw shaft rotates

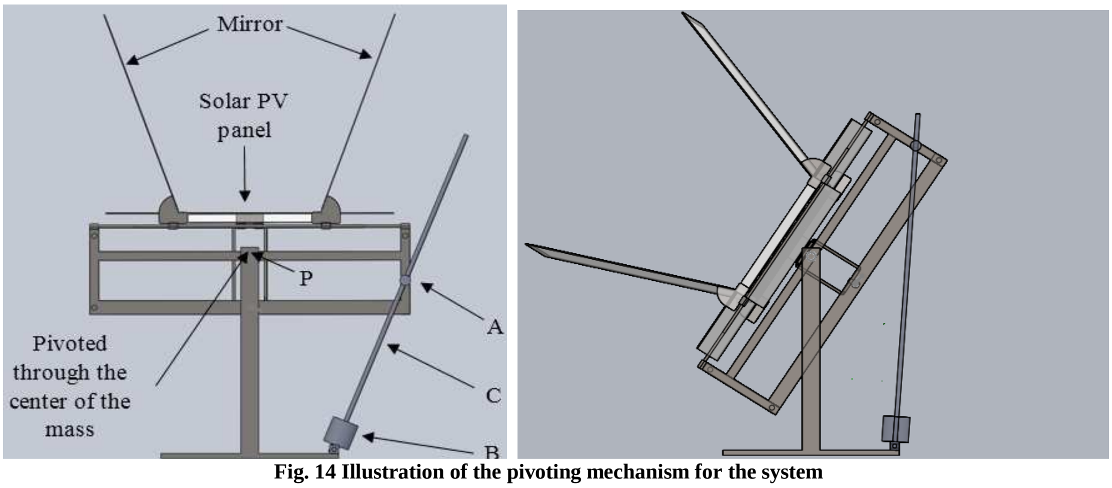

Fig. 14 Illustration of the pivoting mechanism for the system

Since this design focuses the sunlight on to a precise area it is required to keep the solar panel facing the sun at all possible times. The pivoting mechanism is to follow the sun during the day time from dawn to dusk and it has to be adjusted every couple of minutes. This is done through a logic controller and an electric motor. In the model however a programmed micro controller (Arduino) will be used instead of a PLC. Finding the centre of mass of the system and putting the pivoting axis through that would help reduce the torque required to roll the system. The Fig. 14 illustrates the pivoting mechanism in action.

C is a second thread shaft (mentioned as a linear motor previously) used in the same way as the first thread shaft and connected to the solar PV assembly. Instead of tilting the panel this thread bar pivots the whole assembly about the point P. when the electric motor B turns the thread shaft the nut at point A travels along the thread bar thus pulling/pushing the whole assembly with it.

Fig. 15 The model during the testing

RESULTS AND OBSERVATIONS

The solar cell that was used for the experiment is a 21.8 % efficient $125\text{mm} \times 125\text{mm}$ monocrystalline "Sunpower Maxeon" solar cell that has a rated maximum open circuit voltage of 0.574V and a maximum rated short circuit current of 5.83A [1] [13].

$$\text{Therefore the maximum rated current possible} = V_{max} \times I_{max} \quad (1)$$
$$= 0.574\text{V} \times 5.83\text{A}$$
$$= 3.346\text{W}$$

This is generally unachieved in real world conditions although it has to be mentioned that each IBC Poly-Sol 250 GX's power output of 250W is tested under lab conditions of 1000Wm^{-2} radiation at $25^0 C$. [15]

Readings for the open circuit voltage and short circuit current were taken every half an hour from 0800h to 1700h for 3 days, under the conditions in table 4. All the observations are averaged by the readings from 3 separate days with similar weather conditions.

Table -3 The Conditions Under Which The Solar Cell Was Tested

	Cooling method				
	No aided cooling method	Passive cooling with deflector	Active cooling with deflector		
			Electric fan 2m away	Electric fan 1m away	Electric fan 0.5m away
Power output with no solar tracking, no reflectors	A	B	C	D	E
Power output with solar tracking with no reflectors	F	G	H	I	J
Power output with solar tracking and conventional mirrors	K	L	M	N	O
Power output with solar tracking and aluminium foil used as reflectors	P	Q	R	S	T
Power output with solar tracking and aluminium coated paper used as reflectors	U	V	W	X	Y

Power output calculations were done using the equation 1. The values can be found in the table A1 in the appendix A which are then used to plot the Fig. 16.

Table -4 Calculated Total System Cost for the Proposed Solar Array

	Quantity	Unit Cost	Total
IBC PolySol 250 GX 250 watt solar panels	400	$ 138	$ 55,200
Sunny Mini Central 10000T	10	$ 1,378	$ 13,780
Mirrors	800	3.94	$ 3,152
Structure of the solar panels	20	$ 1,129	$ 22,580
Linear motor	20	$ 96	$ 1,920
Copper wire and junction box	20	$ 350	$ 7,000
Grounding wire	1	$ 150	$ 150
System Cost Total			$103,782

Table -A1 The Power Output of the Model under Different Conditions in the Table 4

(Watts)	The condition of the experiment												
	No tracking with no reflectors					Tracking with no reflectors					Tracking with mirrors		
Time of the day	A	B	C	D	E	F	G	H	I	J	K	L	M
0800h	0.11	NA	NA	NA	NA	1.19	1.28	1.17	1.31	1.23	1.44	1.54	1.53
0830h	0.34	NA	NA	NA	NA	1.22	1.35	1.24	1.40	1.29	1.66	1.67	1.90
0900h	1.02	NA	NA	NA	NA	1.80	1.67	1.80	1.78	1.92	1.89	2.02	2.20
0930h	1.33	NA	NA	NA	NA	1.97	1.88	1.97	2.09	1.99	1.98	2.10	2.29
1000h	1.60	NA	NA	NA	NA	2.34	2.43	2.34	2.53	2.50	2.57	2.65	2.44
1030h	2.22	NA	NA	NA	NA	2.56	2.51	2.56	2.49	2.52	2.92	2.90	2.87
1100h	2.40	NA	NA	NA	NA	2.80	2.88	2.75	2.86	2.83	3.11	3.12	2.95
1130h	2.65	NA	NA	NA	NA	2.88	2.87	2.88	2.92	2.89	3.10	3.02	3.11
1200h	2.88	2.93	2.88	2.92	2.90	3.03	3.01	3.06	3.21	3.01	3.03	2.99	3.02
1230h	3.01	3.09	3.01	3.07	3.09	3.01	3.04	3.01	3.10	2.95	3.07	3.03	3.13
1300h	3.11	3.12	3.10	3.09	3.11	3.12	3.03	3.10	3.01	3.11	3.03	3.10	2.84
1330h	3.02	3.09	3.03	3.12	3.11	3.11	3.10	3.11	3.03	3.15	3.12	3.13	3.07
1400h	3.03	3.02	2.98	3.08	3.12	3.14	3.03	3.14	3.07	3.04	3.07	3.04	3.12
1430h	2.99	NA	NA	NA	NA	3.03	3.02	3.00	3.04	3.08	2.98	3.05	3.08
1500h	2.67	NA	NA	NA	NA	2.88	2.78	2.88	2.84	2.88	2.94	2.95	3.03
1530h	2.50	NA	NA	NA	NA	2.86	2.80	2.86	2.56	2.78	2.86	3.02	2.45
1600h	2.30	NA	NA	NA	NA	2.67	2.48	2.67	2.52	2.76	2.77	2.67	2.73
1630h	1.88	NA	NA	NA	NA	2.01	2.22	2.01	2.22	2.16	2.44	2.56	2.22
1700h	0.44	NA	NA	NA	NA	1.55	1.04	1.55	1.34	1.60	2.15	2.14	1.97
0800h	1.67	1.53	1.16	1.28	1.19	1.16	0.66	0.81	0.87	0.93	1.23	1.11	
0830h	1.80	1.90	1.28	1.25	1.34	1.34	1.25	1.78	1.62	1.87	1.99	1.86	
0900h	2.25	2.20	1.78	1.47	1.42	1.56	1.74	2.22	2.04	2.22	2.27	2.20	
0930h	2.28	2.29	1.91	1.88	1.53	1.73	1.81	2.19	2.21	2.33	2.24	2.25	
1000h	2.67	2.44	2.34	2.43	1.80	2.41	2.22	2.65	2.59	2.47	2.54	2.43	
1030h	2.75	2.77	2.55	2.51	2.22	2.23	2.37	2.74	2.78	2.85	2.67	2.72	
1100h	2.87	2.95	2.76	2.85	2.60	2.54	2.71	3.00	3.08	2.95	2.95	2.95	
1130h	3.10	3.12	2.91	2.98	2.75	2.88	2.95	3.11	3.12	3.11	3.10	3.10	
1200h	3.06	3.07	3.03	3.01	2.86	2.98	3.02	3.08	3.06	3.04	3.04	3.11	
1230h	3.13	3.10	3.04	3.02	3.03	3.01	3.09	3.07	3.11	3.13	3.08	3.06	
1300h	3.12	3.09	3.08	3.05	3.11	3.04	3.11	3.11	3.12	3.12	3.01	3.03	
1330h	3.05	3.07	3.10	3.11	3.04	3.12	3.10	3.10	3.11	2.87	3.06	3.12	
1400h	3.12	2.87	3.12	3.14	3.06	3.11	3.07	3.08	3.10	2.95	3.10	3.06	
1430h	2.98	3.03	3.05	2.90	2.97	3.01	2.85	3.07	3.05	3.08	2.97	3.03	
1500h	3.03	3.02	3.04	2.84	2.69	2.84	2.81	2.93	2.97	3.03	3.01	2.99	
1530h	2.49	2.60	2.76	2.56	2.40	2.34	2.42	2.85	2.77	2.47	2.58	2.65	
1600h	2.29	2.56	2.65	2.47	2.36	2.21	2.56	2.32	2.44	2.43	2.72	2.39	
1630h	2.10	2.28	2.18	2.07	2.14	2.03	2.05	2.35	2.56	2.22	2.55	2.21	
1700h	1.54	1.92	1.45	1.65	1.59	1.56	1.67	2.10	2.19	1.96	1.92	1.99	

In the Fig. 16 it can be seen that adding a reflector to an already sunlight saturated PV panel does not make any difference, except increasing the temperature (see Fig. 18) which tends to reduce the lifespan of the solar cells. But the objective of the reflector here was to keep the solar panel at saturated levels even when the sunlight is not at its peak is the benefit which it has achieved. (1000h to 1630h instead of 1115h to 1530h in graph 10). Surprisingly it seems that having an aluminium foil as a reflector does not make any significant difference at all and an aluminium coated papers being a fraction of the cost of a glass mirror, served just as well has a glass mirror itself. Building upon these findings the effectively of the wind deflector calculations will be carried out only for mirror and Al coated paper reflectors using the data from the same table A2 in the appendix.

Table -A2 Performance of the Solar Cell in the Model under Different Wind Conditions

$(Celsius)$	The condition of the experiment												
	No tracking with no reflectors					Tracking with no reflectors					Tracking with mirrors		
Time of the day	A	B	C	D	E	F	G	H	I	J	K	L	M
0800h	0.11	NA	NA	NA	NA	1.19	1.28	1.17	1.31	1.23	NA	1.54	1.53
0830h	0.34	NA	NA	NA	NA	1.22	1.35	1.24	1.40	1.29	NA	1.67	1.90
0900h	1.02	NA	NA	NA	NA	1.80	1.67	1.80	1.78	1.92	NA	2.02	2.20
0930h	1.33	NA	NA	NA	NA	1.97	1.88	1.97	2.09	1.99	NA	2.10	2.29
1000h	1.60	NA	NA	NA	NA	2.34	2.43	2.34	2.53	2.50	NA	2.65	2.44
1030h	2.22	NA	NA	NA	NA	2.56	2.51	2.56	2.49	2.52	NA	2.90	2.87
1100h	2.40	NA	NA	NA	NA	2.80	2.88	2.75	2.86	2.83	NA	3.12	2.95
1130h	2.65	NA	NA	NA	NA	2.88	2.87	2.88	2.92	2.89	NA	3.02	3.11
1200h	2.88	2.93	2.88	2.92	2.90	3.03	3.01	3.06	3.21	3.01	NA	2.99	3.02
1230h	3.01	3.09	3.01	3.07	3.09	3.01	3.04	3.01	3.10	2.95	NA	3.03	3.13
1300h	3.11	3.12	3.10	3.09	3.11	3.12	3.03	3.10	3.01	3.11	NA	3.10	2.84
1330h	62.3	3.09	3.03	3.12	3.11	3.11	3.10	3.11	3.03	3.15	NA	3.13	3.07
1400h	3.03	3.02	2.98	3.08	3.12	3.14	3.03	3.14	3.07	3.04	NA	3.04	3.12
1430h	2.99	NA	NA	NA	NA	3.03	3.02	3.00	3.04	3.08	NA	3.05	3.08
1500h	2.67	NA	NA	NA	NA	2.88	2.78	2.88	2.84	2.88	NA	2.95	3.03
1530h	2.50	NA	NA	NA	NA	2.86	2.80	2.86	2.56	2.78	NA	3.02	2.45
1600h	2.30	NA	NA	NA	NA	2.67	2.48	2.67	2.52	2.76	NA	2.67	2.73
1630h	1.88	NA	NA	NA	NA	2.01	2.22	2.01	2.22	2.16	NA	2.56	2.22
1700h	0.44	NA	NA	NA	NA	1.55	1.04	1.55	1.34	1.60	NA	2.14	1.97

Time of the day	N	O	P	Q	R	S	T	U	V	W	X	Y
0800h	1.67	1.53	NA	1.28	1.19	1.16	0.66	NA	0.87	0.93	1.23	1.11
0830h	1.80	1.90	NA	1.25	1.34	1.34	1.25	NA	1.62	1.87	1.99	1.86
0900h	2.25	2.20	NA	1.47	1.42	1.56	1.74	NA	2.04	2.22	2.27	2.20
0930h	2.28	2.29	NA	1.88	1.53	1.73	1.81	NA	2.21	2.33	2.24	2.25
1000h	2.67	2.44	NA	2.43	1.80	2.41	2.22	NA	2.59	2.47	2.54	2.43
1030h	2.75	2.77	NA	2.51	2.22	2.23	2.37	NA	2.78	2.85	2.67	2.72
1100h	2.87	2.95	NA	2.85	2.60	2.54	2.71	NA	3.08	2.95	2.95	2.95
1130h	3.10	3.12	NA	2.98	2.75	2.88	2.95	NA	3.12	3.11	3.10	3.10
1200h	3.06	3.07	NA	3.01	2.86	2.98	3.02	NA	3.06	3.04	3.04	3.11
1230h	3.13	3.10	NA	3.02	3.03	3.01	3.09	NA	3.11	3.13	3.08	3.06
1300h	3.12	3.09	NA	3.05	3.11	3.04	3.11	NA	3.12	3.12	3.01	3.03
1330h	3.05	3.07	NA	3.11	3.04	3.12	3.10	NA	3.11	2.87	3.06	3.12
1400h	3.12	2.87	NA	3.14	3.06	3.11	3.07	NA	3.10	2.95	3.10	3.06
1430h	2.98	3.03	NA	2.90	2.97	3.01	2.85	NA	3.05	3.08	2.97	3.03
1500h	3.03	3.02	NA	2.84	2.69	2.84	2.81	NA	2.97	3.03	3.01	2.99
1530h	2.49	2.60	NA	2.56	2.40	2.34	2.42	NA	2.77	2.47	2.58	2.65
1600h	2.29	2.56	NA	2.47	2.36	2.21	2.56	NA	2.44	2.43	2.72	2.39
1630h	2.10	2.28	NA	2.07	2.14	2.03	2.05	NA	2.56	2.22	2.55	2.21
1700h	1.54	1.92	NA	1.65	1.59	1.56	1.67	NA	2.19	1.96	1.92	1.99

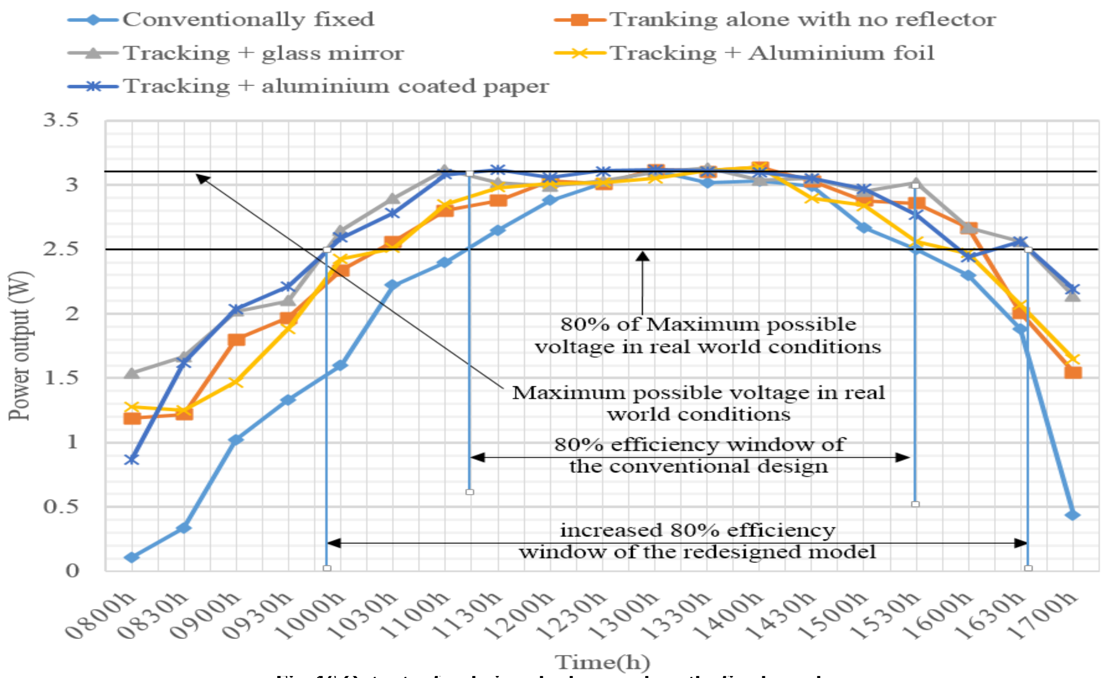

Fig. 16 Outputs of redesigned solar panels vs the fixed panel

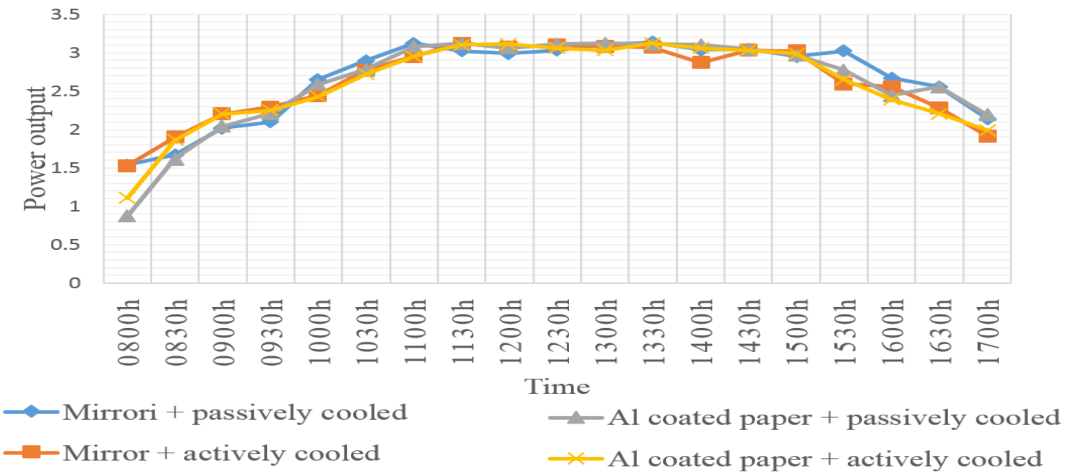

Fig. 17 Different power output values of a solar panel under different wind speeds

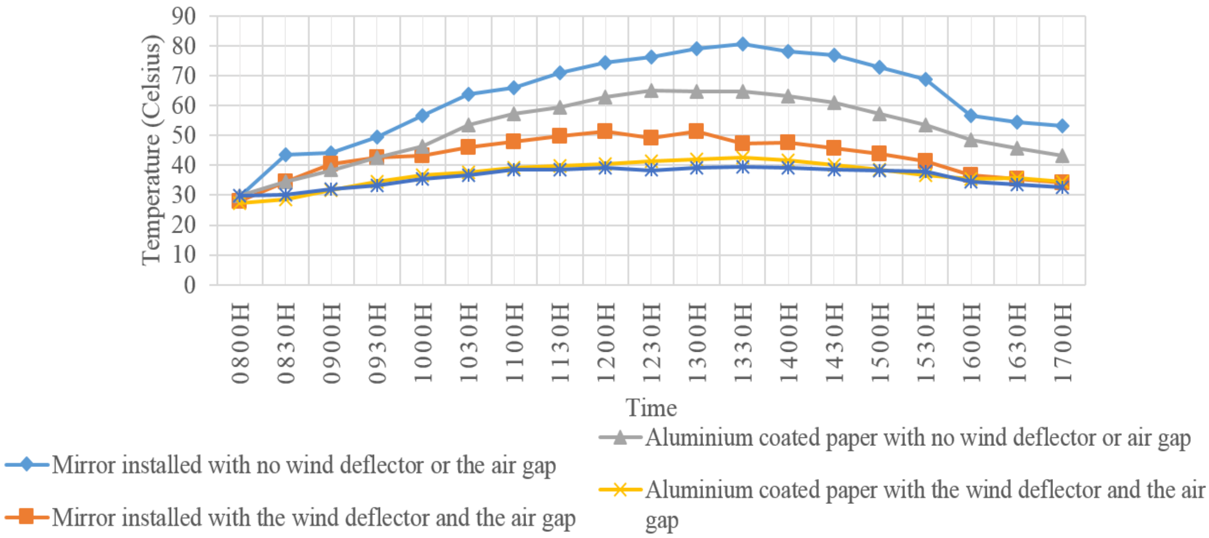

Fig. 18 Temperature readings for mirror and aluminium paper reflectors. Values were taken under passive and active cooling. Note: the active cooling wind speed was approximately set to be as the same speed as the rooftop of the factory. The values can be found in the table A3 in the appendix A

As it seen on the Fig. 17 the wind deflectors had not affected the power output of the solar panel in any significant manner either. But with the temperature data available on the Fig. 18 and IBC PolySol 250 GX's nominal operating cell temperature of 40^0C [15] it is seems that the lower temperature in the model that had Aluminium coated paper would be the best technical option. But considering the longer lifespan of a glass mirror and its ability to resist extreme weather conditions far outweighs the advantages of the aluminium coated paper.

Table -A3 Temperature readings from the solar cell in the model at different wind speeds

(*Celsius*)	Conditions			
Time of the day	Mirror with passive cooling	Mirror with Active cooling	Aluminium coated paper with passive cooling	Aluminium coated paper with active cooling
0800h	29.4	28.1	29.8	27.2
0830h	43.6	34.5	34.6	28.5
0900h	44.2	40.4	38.4	31.8
0930h	49.4	42.6	42.7	34.4
1000h	56.6	43.2	46.3	36.6
1030h	63.9	46.1	53.6	37.5
1100h	66.1	47.9	57.3	39.3
1130h	71.1	49.7	59.5	39.8
1200h	74.3	51.4	62.8	40.5
1230h	76.4	49.1	64.9	41.5
1300h	79.2	51.2	64.7	41.9
1330h	80.5	47.4	64.8	42.5
1400h	78.2	47.6	63.3	41.8
1430h	76.8	45.8	61.1	40.2
1500h	72.9	43.9	57.3	38.7
1530h	68.7	41.5	53.5	36.6
1600h	56.5	36.6	48.5	35.3
1630h	54.4	35.4	45.7	35.8
1700h	53.1	34.2	43.2	34.4

Table -5 Payback Period Calculation for the Proposed System

Number of Panels	400
Watts Per Panel	250 W
Total watts per hour assuming optimum conditions	100,000 W
Number of hours that has adequate amount of sunlight*	7.0 h
Estimated kilowatt hours per day output	700 kWh
Number of days per month with bright day light estimated	20
Estimated kWh per month output	14000 kWh
Leaving 5% to power the tracking mechanism	13300 kWh
Buying rate of a kWh in peak time (from the grid) converted to USD	0.16 $
Money saved from an average month	2128 $
Total payback period of the system	48.77 months

Table -6 Calculated Total System Cost for a Conventionally Mounted Solar PV Array

	Quantity	Unit Cost	Total
IBC PolySol 250 GX 250 watt solar panels	400	$ 138	$ 55,200
Sunny Mini Central10000T	10	$ 1,378	$ 13,780
Mirrors	0	3.94	$ -
Structure of the solar panels	20	$ 321	$ 6,420
Linear motor	0	$ 96	$ -
Copper wire and junction box	20	$ 350	$ 7,000
Grounding wire	1	$ 150	$ 150
System Cost Total			$82,550

Table -7 Payback Period Calculation for a Conventionally Mounted Solar PV Array

Number of Panels	400
Watts Per Panel	250 W
Total watts per hour assuming optimum conditions	100,000 W
Number of hours that has adequate amount of solar power*	4.3 h
Estimated kilowatt hours per day output	430 kWh
Number of working days per month with bright day light	20
Estimated kWh per month output	8600 kWh
Buying rate of a kWh in peak time (from the grid) converted to USD	0.16 $
Money saved from an average month	1376 $
Total payback period of the system	75.42 months

*The number of hours is increased by the use of reflectors. The window of the maximum efficiency has widened.

The breakeven analysis was done using the pricings and net metering pricings available in Sri Lanka. The client has an energy requirement of 1020kWh in peak hours and 675kWh in off peak hours per month and a peak electrical demand of 200kW (value taken from the backup generator output values, which was outdated and a data sheet was not available). The solar panels are set to initially produce 50% of the company's peak electricity demand which is 100kW. The inverter proposed for the solar system is Sunny Mini Central10000T of which the maximum DC power input from the solar panels is 10350W and had a price tag of 1378$ [17-18] and therefore it is decided to use 10 of them along with 400 (250W) solar panels. The panel array will be configured in 20 rows of 20 panels each, due to the narrow and long roof shape. Therefore 20 sets of proposed mechanical rails will be used along with 20 linear actuators.

CONCLUSIONS

Implementing a solar tracker mechanism does improve the power output of a conventional solar panel during the morning and the evening hours. Adding a reflector to harness additional sunlight on to the panel makes a difference only when the solar panel has not yet reached its peak performance. The objective of the design which was to widen the window in of maximum power output has been achieved. Adding a reflector increases the temperature of the PV panel and it seems that having a wind deflector to funnel the air in to the air gap and then onto the solar panel does seem to reduce the temperature marginally. The temperature of the PV panel did not have an immediate effect on the solar panel output. But the increased temperature might affect the efficiency of the solar panel in the longer run. Implementing the design has reduced the payback period of the solar array. And based on the calculations, the redesigned array will continue to produce significantly higher amount of power even after the payback period. Having a mechanised solar panel that tracks and follows the sun instead of a fixed panel which does not have any moving parts might introduce the chance of mechanical a failure. In a chance of a solar tracker failure the power output will plummet as the mirrors might cast a shadow on the solar panel. And also the mechanised solar panel and its almost vertical mirrors will not hold as much as a permanently mounted solar array under extreme weather conditions and it might require some maintenance time to time.

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