International Journal on Emerging Technologies **12**(1): 43-47(2021)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

Experimental Study of Solar Chimney Cooled 40Wp Solar PV Panel

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(Received 03 October 2020, Revised 18 December 2020, Accepted 07 January 2021)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Temperature plays very important role in the performance of solar PV systems as the increased cell temperature reduces the efficiency and power output of solar PV cell. This paper presents an experimental study of cooling effect on 40Wp solar PV by using solar chimney, a passive method. A comparison of the performance between hybridized 40Wp solar PV with solar chimney and standard 40Wp solar PV is also presented.

Keywords: Solar Chimney, Solar PV cooling.

I. INTRODUCTION

Energy requirement is increasing all over the world and about 80% is supplied by fossil fuel based energy sources i.e. coal, gas and oil [1]. Owing to the rapid exhaustion of conventional energy sources and their impact on environment, renewable energy resources based systems are preferred. They are finding more and more acceptability since they are pollution free, eco-friendly and have become cost effective also. Solar energy is free and easily available. A little bit of solar energy is utilized to produce electrical energy while remaining converted into heat which increases the temperature of PV panels. The reverse saturation current of a solar cell rises speedily with temperature which reduces the cell voltage and in turn energy yield.

Many researchers have concluded that overall performance of SPV cell falls significantly with the increase in temperature. The reduction in efficiency ranges from 0.25 to 0.5% per ^{o}C rise in temperature depending on the cell material [2-7]. The current-voltage (I-V) characteristics are also affected by the cell's temperature. Open circuit voltage (V_{oc}) and the maximum generated power (P_{max}) decrease rapidly with the increase in temperature due to fast rise in reverse saturation current. PV panel temperature increases, resulting in marginal increase in the cell current although a notable drop in voltage. The efficiency can be increased by 3-5% by cooling of PV panel [8].

This paper presents experimental study of 40Wp solar PV cooling by providing solar chimney and compares the performance of 40Wp solar PV panel with the same 40Wp solar PV panel with solar chimney at Rabindranath Tagore University, Raisen, Madhya Pradesh, India.

II. ARRANGEMENTS OF SOLAR CHIMNEY USED IN RESIDENTIAL APPLICATIONS

It works on the principle of stack effect (temperature difference), pressure is developed through deviations in air density with change in temperature that results in rise of hot air and sink of cold air. Arrangements of solar chimney used in residential applications are roof top. The air gets heated from hot solar chimney plates and walls, due to buoyancy drive, air comes out of the chimney and released in the atmosphere. In this, solar chimney draws air from interior room or space and replaces it by the fresh air through openings located in lower heights, this process is called natural ventilation, its rate depends on various factors, such as capability of heat absorbing plate, angle of inclination, cross sectional area of inlet and outlet vent [9, 10]. Solar chimney can be employed in a variety of applications i.e. natural ventilation, power generation, space cooling, food drying, etc.

III. EXPERIMENTAL SET-UP OF 40WP SOLAR PV PANEL AND SOLAR CHIMNEY HYBRID SYSTEM

Two Experimental set-ups are installed at rooftop in the campus of Rabindranath Tagore University, Bhopal, (*latitude* 23° 15' N, and *longitude* 77° 24' E) and 527m above sea level. Following two rooftop experimental set-ups were made:

Set-up 'A': A standard 40Wp solar PV panel, shown in Fig. 1.

System 'B': A hybrid 40Wp solar PV with solar chimney, shown in Fig. 2.

Fig. 1. Set-up 'A' (i.e. 40W solar PV panel).

Fig. 2. Set-up 'B' (i.e. 40W solar PV panel with solar chimney).

Experimental set-up 'A'
Specifications of experimental set-up 'A' are given in Table 1. It is orientated to the south and the tilt angle of the solar cell was equal to latitude i.e. 23.25°. The experimental set-up is shown in Fig. 1.

Experimental set-up 'B'
Specifications of experimental set-up 'B' are given in Table 2. It is orientated to south and the tilt angle of the solar panel was equal to latitude i.e. 23.25°, as shown in Fig. 2.

Table 1: Description of experimental set-up 'A'.

Particulars	Description	Remarks
Solar panel	A 40Wp solar PV panel (90cm × 60cm (L × W)).	Ref Fig. 1
	One temperature sensors (The MCP9700 type) are fitted in different locations T_4, at back side of solar PV panel	Ref Fig. 1
Display board	One electronic LCD display is installed, common for both experimental set-up A & B.	Ref Fig. 5
Stand	It is made up of iron to hold solar panel.	Ref Fig. 1

Table 2: Description of experimental set-up 'B'.

Particulars	Description	Remarks
Top part of air duct	It's rectangular duct 123 cm × 64 cm × 8 cm (L × W × H), is vertically attached with middle part of air duct (i.e. towards glass mounting) to act as chimney. It is made of cast iron sheet. It can be braked up in three pieces of same dimension (41 cm × 64 cm × 8 cm (L × W × H), to vary the chimney height.	Ref Fig. 4
Middle part of air duct	Material: Cast iron sheet. Dimensions: 166cm × 64cm × 8cm (L×W×H).	Ref Fig. 3
	A transparent glass (70cm × 60cm (L × W)) and a 40Wp solar PV panel (90cm × 60cm (L × W)) are mounted, at upper and lower portion respectively, on the top view of middle part of air duct.	Ref Fig. 3
	Just opposite to glass view 74cm × 64 m (L × W) i.e. inner cast iron sheet of air duct, is painted in black color to absorb solar heat.	Ref Fig. 3
Lower part of air duct	It is a rectangular air duct (41 cm × 64 cm × 8 cm (L × W × H), and attached to the lower portion of the middle part of air duct (i.e. towards solar PV mounted) to suck air. It is made of cast iron sheet.	Ref Fig. 3
	Three 12 VDC fans are fitted at lower portion of lower part of air duct to achieve desired air velocity and air mass flow rate.	Ref Fig. 3
	Three temperature sensors (The MCP9700 type) are fitted at different locations T_1, at middle point of inlet air T_2, at back side of solar PV panel T_3, at bottom of middle part of air duct that is black colored & just back side of glass mounting.	
Battery	12 V, 10 Ah battery to provide power supply to fan and LCD display.	
Display board	One electronic LCD display panel: to display voltage output (V_{oc}) and temperature. It is common for both experimental set-ups 'A' & 'B'.	Ref Fig. 5
Speed controller	It is a potentiometer, acts as an adjustable voltage divider.	Ref Fig. 5

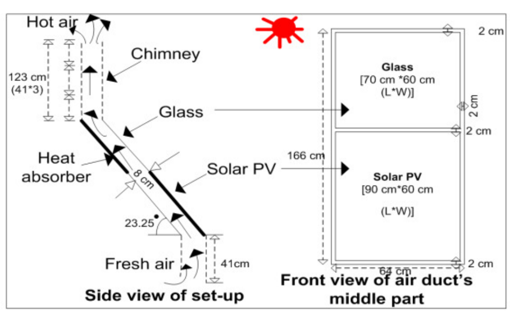

Fig. 3. Schematic of Set-up 'B' (i.e. hybrid solar PV with solar chimney).

Fig. 4. Arrangement for adjustment of the height of chimney.

Fig. 5. Display panel.

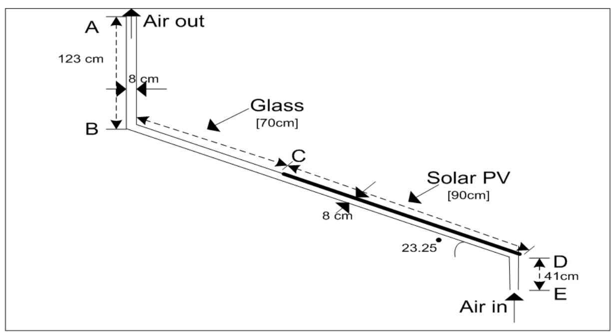

Fig. 6. Side-view of Set-up 'B'

Different modes of experiment. The tests were carried out in four modes as given below and described in Table 3.

Table 3: Operation modes.

Set-up	Modes	Description
Set-up 'B'	Mode-I	40Wp solar PV panel with chimney height = 41 cm
	Mode-II	40Wp solar PV panel with chimney height = 82 cm
	Mode-III	40Wp solar PV panel with chimney height = 123 cm
Set-up 'A'	Mode-IV	40Wp solar PV panel

IV. PERFORMANCE EVALUATION OF EXPERIMENTAL SET-UPS 'A' AND 'B'

Both systems were set facing towards south direction with the inclined angle (23.25°) to gain the maximum solar radiation readings taken at clear days. At the beginning of each test, the glass cover and solar cell were thoroughly cleaned. The measurements of temperature, air velocity/mass flow rate and voltage output (V_{oc}) were recorded from morning 10 AM to evening.

Test was performed in many hot days during summer (March 2017-May 2017). Test results of extreme peak summer days of season i.e. 15th May 2017 to 22nd May 2017 are presented here.

Each mode tested on alternative days. Same test was conducted during winter (October-December 2017 and January-February 2018) season at Bhopal. Test results of intensive winter days 21st December to 28th December 2017 are presented here. Open circuit voltage (V_{oc}) of solar panel and air temperatures (T_1, T_2, T_3) were recorded at different heights (41, 82, 123 cm) of chimney and air mass flow rates. Where,

V_{oc} = Open circuit voltage of solar panel,

T_1 = inlet air temp,

T_2 = air temperature at back side of solar panel,

T_3 = air temp at black colored bottom sheet of middle part of air duct just below the glass mounting.

Temperatures (T_1, T_2, T_3) for Mode- I, II & III are same, thus paper presents temperatures only for Mode-III. Temperatures (T_1, T_2, T_3) for Mode-III (i.e. height of chimney = 123 cm) during summer season are given in Table 4.

Performance of Solar PV (V_{oc}) in mode-III is given in Table 5.

V_{oc} and Temperature (T_4) of panel for Mode-IV (i.e. solar PV without modification) during summer season are presented in Table 6.

Comparison of V_{oc} between Mode-III (for 1.26 kg/s mass flow rate, refer Table 5, at sr. no. 3 i.e. SN3) & Mode-IV, that reflects increase in V_{oc} in Mode-III due to modification, during summer season is shown in Fig. 7.

Temperatures (T_1, T_2, T_3) for Mode-III (i.e. height of chimney is 123 cm) during winter season are given in Table 7.

Performance of Solar PV (V_{oc}) at Mode-III (i.e. height of chimney is 123 cm) during winter season is presented in Table 8.

Table 4: Temperatures (T_1, T_2, T_3) for Mode-III on May 15, 2017.

Sr. No.	Mass flow rate (kg/s)	Temperature (°C)														
		10 AM			12 PM			2 PM			4 PM			6 PM		
		T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
1	0.42	26	29	34	30	35	45	33	39	52	35	42	73	34	40	69
2	0.84	28	27	34	30	34	47	33	38	58	35	40	75	34	38	71
3	1.26	27	27	38	31	32	48	34	36	60	36	39	78	35	37	71

Table 5: Performance of Solar PV (V_{oc}) panel in Mode-III on May 15 & 16, 2017.

Sr. No.	Mass flow rate (kg/s)	V_{oc} of panel (V)				
		10 AM	12 PM	2 PM	4 PM	6 PM
1	0.42	19.7	19.6	19.7	19.5	19.5
2	0.84	19.9	20.0	20.1	19.9	19.9
3	1.26	20.2	20.3	20.4	20.2	20.2

Table 6: V_{oc} and Temperature of panel for mode-IV on May 22, 2017.

Time	Temperature of panel (ave. of T_4) (°C)	V_{oc} of panel (V)
10AM	32	19.1
12PM	39	19.2
2PM	42	19.0
4PM	44	19.0
6PM	38	18.9

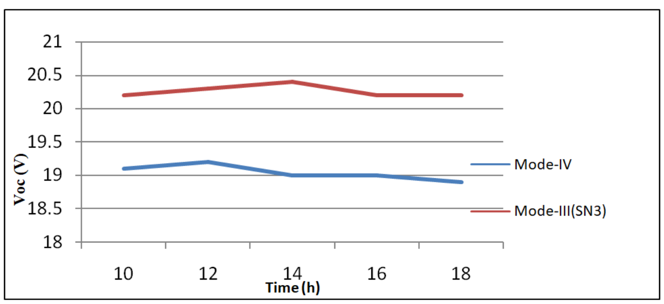

Fig. 7. Comparison of Voc in Mode-III & IV during summer.

Table 7: Temperatures (T_1, T_2, T_3) for Mode-III on Dec 21, 2017.

Sr. No.	Mass flow rate (kg/s)	Temperature (°C)														
		10 AM			12 PM			2 PM			4 PM			5 PM		
		T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
1	0.42	15	18	24	18	23	35	20	27	40	18	24	44	15	20	34
2	0.84	16	18	24	19	23	37	20	26	45	19	24	50	16	18	38
3	1.26	16	17	28	18	22	38	20	25	48	18	22	55	16	17	40

Table 8: Performance of Solar PV (V_{oc}) in Mode-III on Dec 21 & 22, 2017.

Sr. No.	Mass flow rate (kg/s)	V_{oc} of panel (V)				
		10 AM	12 PM	2 PM	4 PM	5 PM
1	0.42	17.8	18.0	17.9	17.7	17.7
2	0.84	17.9	18.2	18.2	17.9	17.9
3	1.26	18.3	18.4	18.5	18.3	18.1

V_{oc} and Temperature (T_4) of panel for Mode-IV (i.e. solar PV without modification) during winter season are given in Table 9.

Comparison of V_{oc} between Mode-III (for 1.26 kg/s mass flow rate, refer Table 7, at sr. no. 3 i.e. SN3) & Mode-IV that reflects increase in V_{oc} in Mode-III due to modification, during winter season is shown in Fig. 8.

Table 9: V_{oc} and Temperature of panel for mode-IV on Dec 28, 2017.

Time	Temperature of panel (ave. of T_4) (^oC)	V_{oc} of panel (V)
10AM	20.2	17.2
12PM	23.2	17.7
2PM	25.4	17.9
4PM	26.1	17.5
5PM	24.2	17.0

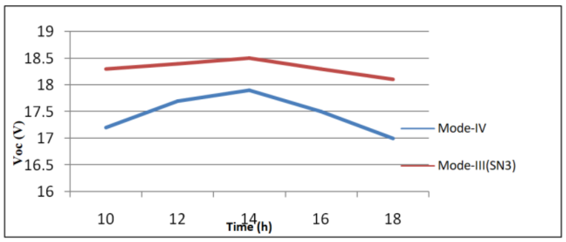

Fig. 8. Comparison of Voc in Mode-III & IV during winter.

V. CONCLUSION

The performance of Solar PV system can be improved by cooling it through active and passive techniques. Due to environmental issues, passive techniques are desirable. This experimental analysis focused on investigation of cooling effect on 40Wp solar PV by using passive method i.e. solar chimney. Effect of various parameters are studied, they are as follows:

(i) Adjusting air mass flow rate

It is observed that voltage output (V_{oc}) of solar panel increased by 3-5% by maintaining appropriate air mass flow rate by installing fans. Without fans (i.e. natural air ventilation system), the temperature of air on back side of solar panel reaches in the range 45-50 ^oC that results in drastic reduction in V_{oc} by 50-60%.

(ii) Effect of adjusting height of chimney

It is observed from test results that increasing height of chimney from 41 cm to 82 or 123 cm does not change air mass flow rate and cooling effect on the solar panel. In the present experimental setup dimensions of top part of air duct are maintained same i.e. 64 cm × 8 cm (W × H) for different lengths i.e. 41, 82, 123 cm. It is concluded that design of top part of air duct must be considered with its adjusting length.

(iii) Seasonal effect

During summer season voltage output (V_{oc}) is about 10% higher than winter.

(iv) By product

Dry hot air comes out from chimney at a temperature of 65-75 ^oC during summer and 50-55 ^oC during winter. It can be used for drying purpose.

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How to cite this article: Soni, U. K., Soni, S. K. and Awasthi, S. R. (2021). Experimental Study of Solar Chimney Cooled 40Wp Solar PV Panel. *International Journal on Emerging Technologies, 12*(1): 43–47.