



Effect of seasonal variation on the performance of solar photovoltaic pumping system under field conditions

MAHEKPREET KAUR¹, SUNIL GARG², RAKESH SHARDA³ and KAMAL GURMIT SINGH⁴

Punjab Agricultural University, Ludhiana, Punjab 141 004, India

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ABSTRACT

The present study was undertaken to analyse the performance of solar photovoltaic (SPV) pumping system parameters, under different seasons. The average flow rate in summer, monsoon, post-monsoon and winter season was 3.0, 2.17, 3.44 and 2.93 Lps, respectively. The average conversion efficiency in summer, monsoon, post-monsoon and winter season was 14.36, 15.13, 17.04 and 16.85%, respectively. The range of optimum panel temperature should be between 12–32°C at which conversion efficiency will be maximum varying from 18.39–21%. During smog the average solar irradiance and flow rate decreased from 828 W/m² to 393 W/m² and 3.09 Lps to 1.59 Lps, respectively, as compared to before smog conditions. The presence of clouds significantly affected/lowered down the current, RPM and flow rate but the temperature did not change much which reveals that temperature has minimum effect on the development of current and voltage in solar photovoltaic cells.

Key words: Cloud effect, Conversion efficiency, Panel temperature, Smog effect, Solar photovoltaic

Energy demand is increasing for all energy consuming sectors, including agriculture, which is one of the highest energy consumer. From last several decades, India's per capita energy use has increased from 16.3 kWh in 1947 to 1075 kWh in 2015-16. However the installed capacity of India has increased from 1362 MW in 1947 to 344.4 GW as on Jan 31st, 2018 (Ministry of Power, GoI 2018). If the energy demand keeps on increasing then in future India will have to import the conventional fuels sources from other countries. Even with high installed capacity of 344.4 GW still many villages of India have no electricity and also in the areas having electricity the energy demand is increasing at a fast pace due to urbanization and industrialization. Thus it is important to shift to renewable energy sources to meet the increasing energy demands of the country. Solar photovoltaic (SPV) energy is one of the alternative energy sources, which is abundantly available in India and is also pollution-free (Bather and Caruthers 1981). In order to grow the crop where the electricity doesn't reach the farmers the solar photovoltaic system plays a crucial role. Thus, PV based pumping systems is important to use, as electricity is not a reliable source (only 6-8 h supply to farmers in Punjab, India) and also the cost of conventional fuels is

increasing day by day, hence using a PV system operating above 7.2 KW are feasible to use.

Sumathy *et al.* (1997) carried out a study to determine the performance of solar pumping system. The results showed that overall efficiency and the number of cycles increase with increasing solar irradiance, while the number of cycles increase initially up to ambient temperature of 30°C and thereafter decrease. Agrawal and Kale (2006) conducted a study to enhance the daily discharge of a solar photovoltaic pumping system in cloudy as well as in clear weather. Hamrouni *et al.* (2009) analysed the influence of the solar radiation variation on the performances of a stand-alone photovoltaic pumping system. Munir *et al.* (2012) carried out a study for evaluating the performance of a solar powered PV pumping system and concluded that the flow of the pumping unit started when the solar radiation were at an intensity of 100 W/m² and at 650W/m² becomes smooth. Garg *et al.* (2013) carried out a study to determine the performance of solar PV pumping system. The solar irradiance varies from 6.7 to 7.4 k Wh/m² day and the conversion efficiency varies from 2.78–7.42%. Vasisht *et al.* (2016) carried out experiment to define module efficiency of a Solar Photovoltaic (SPV) system in different seasons.

Factors such as season, latitude, air pollution and cloudiness determine the performance of a solar photovoltaic (SPV) pumping system. Hence, detailed information about the performance of SPV pumping system will provide valuable information for the prediction of system's

^{1,2,3,4}(maheaneja@yahoo.com, sunil1765@pau.edu, rakeshsharda@pau.edu, kamalgurmit@pau.edu), Soil and Water Engineering Department.

performance. Keeping in view the high initial investment for this system, it is important to know the conversion efficiency of PV array as well as the overall efficiency of the solar pumping system under different seasons. Hence, the objective of the study is to evaluate the performance of a solar PV pumping system under different seasons, so that the user must be confident about returns as well as trouble free and efficient operation.

MATERIALS AND METHODS

The experimental site was selected at research Farm, Ludhiana, Punjab (latitude 30°54'5", longitude 75°48'10" and altitude of 244 m). It consists of a solar photovoltaic pumping system which comprises of SPV array and submersible pump set. The water table depth at the site was 30 m. The SPV array had automated tracking system. It consist of four SPV panels—1 of which consists of 10 modules and other 3 panels consist of 8 SPV modules each. Therefore, the total number of SPV modules was 34. The total surface area of the present array is 51m² having width of 1.0 m and length of 1.5 m. The submersible pump set is of 7.5 hp (Fig. 1).

The other specifications of SPV panels are given here.

Model	: GOLD1200PM_72S
Peak power output (P_{max})	: 200W $\pm$ 3%
Open circuit voltage (V_{OC})	: 44 V
Short Circuit Current (I_{SC})	: 6.05 A

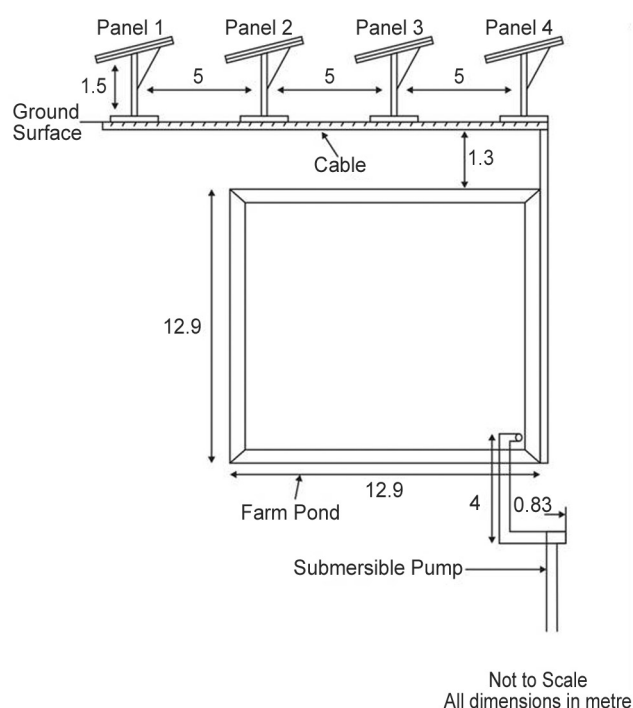


Fig 1 Layout of solar photovoltaic (SPV) pumping system

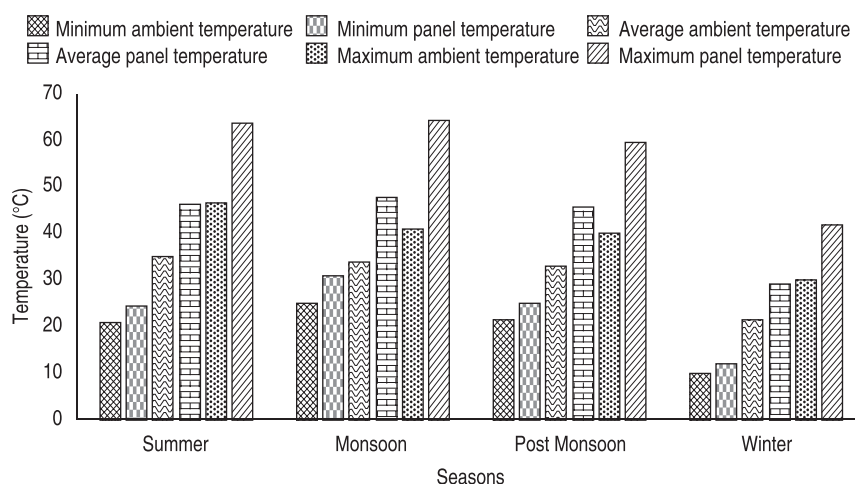


Fig 2 Ambient and panel temperature under different seasons

Voltage at Maximum Power (V_{map}) : 35.8V

Current at maximum power (I_{max}) : 5.60A

Maximum System Voltage : 1000 V

Power measured at standard testing conditions : Irradiation : 1000 W/m²

Temperature : 25°C

The flow rate of the system was measured using volumetric method and other observations like solar radiation, temperature, panel temperature and array output were measured using solar meter, thermometer, infrared thermometer and online software, respectively. The readings were taken on hourly basis starting from 8:00 to 16:00. From the observed parameters the conversion efficiency of the solar photovoltaic system was measured using the formula:

$$\eta_{conv} = \frac{\text{Array output (watts / m}^2\text{)} \times 100}{\text{Total input energy (watts / m}^2\text{)}} \quad (1)$$

Where, η_{conv} = conversion efficiency

$$\text{Array output} = \text{voltage (V)} * \text{current (I)} \quad (2)$$

The different seasons considered are summer (March to June), monsoon (July and August), post-monsoon (September and October) and winter (November to February).

RESULTS AND DISCUSSION

Ambient and panel temperature under different seasons:

The variation of ambient and panel temperature under different seasons (Fig. 2) showed that the maximum ambient temperature (46.5°C) during summer making it hottest and minimum temperature (30°C) in winter making it coolest season. As the ambient temperature rises, panel temperature also increases vice versa. The maximum panel temperature was 64.09°C during monsoon followed by summer 63.45°C, post-monsoon 59.28°C and 41.9°C during winter season.

Solar irradiance under different seasons: The minimum average solar irradiance was found in winter season (623.27 W/m²), while the maximum average solar irradiance (785 W/m²) was found in summer season (Fig 3). The maximum variation in maximum and minimum solar irradiance round the year was found in monsoon due to dip and rise in ambient

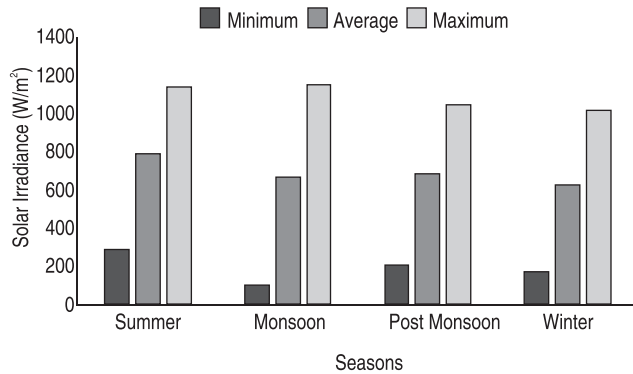


Fig 3 Solar irradiance under different seasons.

and panel temperature (Fig 3). This much variation in solar irradiance is the reason for higher panel temperature in monsoon season.

Array output under different seasons: There was visible effect of array output under different seasons (Fig 4). The minimum average array output was observed in monsoon season (4602 W) due to lower solar irradiance and higher panel temperature. The maximum average array output was observed in post-monsoon season (5704W) due to higher solar irradiance and lower panel temperature. The array output varied between 1460 W and 7728 W around the year.

Flow rate under different seasons: The minimum average flow rate was found in monsoon season (2.17 Lps) due to lower array output of the system and maximum average flow rate was found in post-monsoon season (3.44 Lps) due to high array output of the system (Fig 5). The average flow rate varied from 2.17 Lps to 3.44 Lps for all the seasons. The average flow rate of 2.89 Lps was observed round the year.

Conversion efficiency under different seasons: The minimum average conversion efficiency was observed in summer (14.36%) and maximum average conversion efficiency was found in post monsoon (17.04%) and winter season (16.85%) (Fig 6). Best performance was observed in post-monsoon and winter showed that maximum use of solar radiations was done in these seasons. Due to lower panel temperature the voltage generation is increased, resulting in higher array output which leads to increase in conversion

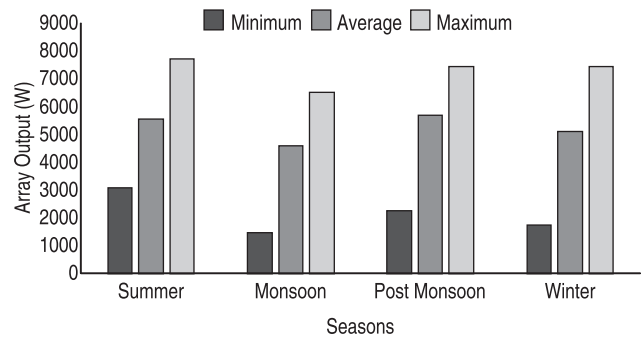


Fig 4 Array output under different seasons.

efficiency at same solar irradiance and these results are in accordance with Vashist *et al.* (2016). The minimum average and maximum conversion efficiency varies from 9.27–10.49%, 14.36–16.85% and 21.71–22.96%, respectively for all the seasons indicating not much variation which states that SPV system can be used round the year.

Solar Insolation and Flow Rate under Different Seasons: The maximum average daily insolation was 7263.93 Wh/m²/day in summer followed by post-monsoon (6153.96 Wh/m²/day) and minimum solar insolation was 4168.69 Wh/m²/day in winter season. The maximum average daily flow rate was in summer (110.70 m³/h/day) followed by post-monsoon (105.93 m³/h/day) and the minimum average daily discharge was in monsoon season (75.16 m³/h/day) due to higher panel temperature resulting in lower array output (Table 1).

The insolation depended upon the time of day and weather condition i.e. cloudy or sunny. Solar insolation showed a parabolic curve like trend throughout the day starting from low values to maximum at noon and then decreasing in the evening (Fig. 7). During morning and evening h, the solar radiations have to travel a long way through the air column which converts most of the solar radiations to diffuse radiation and beam radiations component is reduced. Beam radiations are the solar radiations reaching the earth without being scattered by the atmosphere. Different seasons have different curves due to sun declination angle which results in different sun rise and sun set timings.

Variation of flow rate with time under different seasons: The flow rate was measured at one h intervals during the

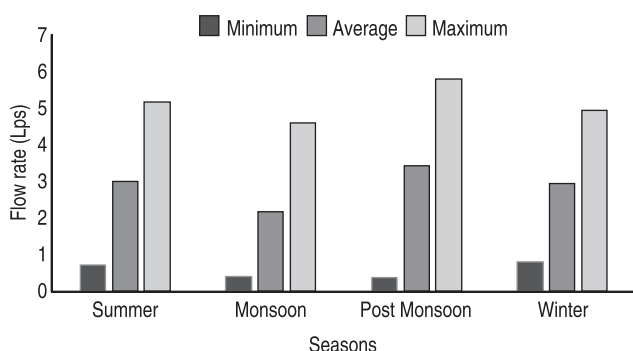


Fig 5 Flow rate under different seasons.

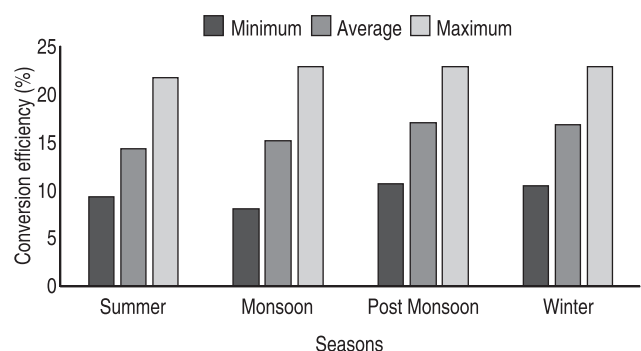


Fig 6 Conversion efficiency under different seasons.

Table 1 Solar insolation and flow rate with time under different season

Time	Season							
	Summer		Monsoon		Post-Monsoon		Winter	
	Solar Insolation (Wh/m ² /h)	Flow Rate (m ³ /h)	Solar Insolation (Wh/m ² /h)	Flow Rate (m ³ /h)	Solar Insolation (Wh/m ² /h)	Flow Rate (m ³ /h)	Solar Insolation (Wh/m ² /h)	Flow Rate (m ³ /h)
06:00	41.37	0.00	11.87	0.00	17.59	0.00		
07:00	172.92	0.00	92.17	0.00	91.79	0.00	61.70	0
08:00	582.56	5.49	275.61	6.36	439.54	4.06	94.46	0
09:00	711.92	11.31	418.64	7.63	553.15	11.18	337.27	8.825
10:00	762.78	12.43	458.81	6.77	661.66	12.02	504.93	11.08
11:00	807.28	13.51	510.17	8.07	709.98	12.47	585.87	11.18
12:00	837.83	14.20	570.91	9.57	697.02	12.09	623.42	11.86
13:00	870.67	13.68	553.82	9.07	708.45	13.38	641.55	11.61
14:00	771.75	13.58	584.59	8.44	754.99	12.92	605.02	11.51
15:00	737.28	12.16	540.10	8.07	707.58	12.14	509.28	10.52
16:00	680.45	10.82	483.25	8.07	579.09	10.76	361.35	7.41
17:00	501.41	3.53	419.92	3.08	342.50	4.93	67.00	0
18:00	107.81	0.00	76.10	0.00	84.77	0.00	-	-
Daily average	7263.93	110.7	4815.82	75.16	6153.96	105.94	4168.69	83.98
Seasonal average	661017.63	10073	298581.0	4660	375392.0	6461	254290.1	5123

sunshine h (Fig. 8). It is evident that summer and post-monsoon season have maximum flow rate and also have a gradual change in flow rate with time. After summer the flow rate decreases in monsoon season due to increased panel temperature, clouds and rainfall. In post-monsoon season again flow rate increases due to decreased panel temperature.

Solar insolation and amount of water pumped under different seasons: During summer solar insolation (661017 Wh/m²) and water pumped (10073.31 m³) was maximum, followed by post-monsoon season. The minimum solar insolation was in winter season (254290.1 Wh/m²) while the water pumped was minimum in monsoon season (4659.61 m³) due to lower array output (Fig 9).

Effect of Smog on SPV System Parameter: The effect of thick layer smog due to stubble burning from 30th October

2017 to 14th November 2017 followed by rain on various SPV parameters was studied. The variation in minimum, average and maximum values of ambient temperature,

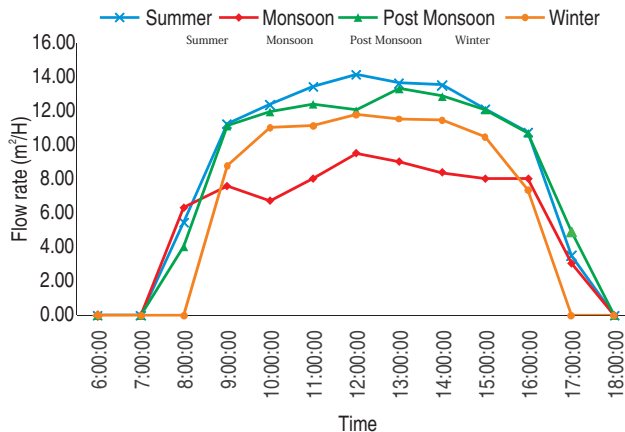


Fig 8 Variation of flow rate with time under different seasons.

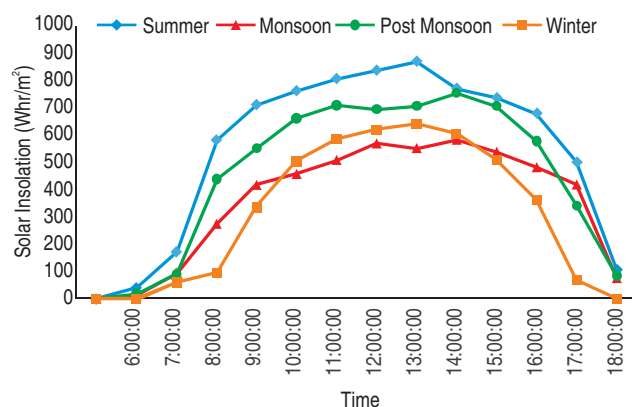


Fig 7 Variation of solar insolation with time under different seasons.

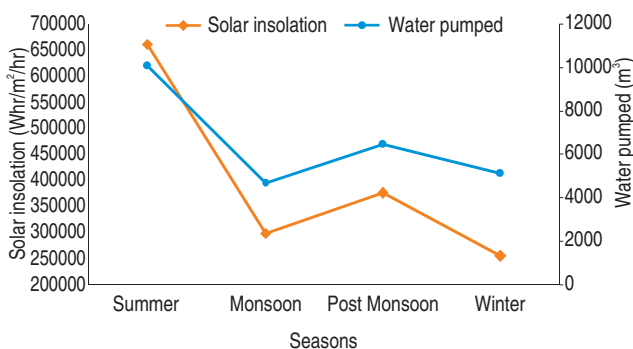


Fig 9 Variation of solar insolation and water pumped under different seasons.

Table 2 Effect of smog on SPV system parameter

Parameter		Before smog	During smog
Ambient temperature (°C)	Minimum	24.00	14.00
	Maximum	34.00	30.00
	Average	29.30	24.25
Panel temperature (°C)	Minimum	32.00	22.48
	Maximum	48.10	41.90
	Average	40.12	31.27
Solar irradiance (W/m ²)	Minimum	555	204
	Maximum	979	713
	Average	828	393
Array output (W)	Minimum	4368	2176
	Maximum	6039	5880
	Average	5596	3305
Flow rate (Lps)	Minimum	2.36	0.93
	Maximum	3.42	3.38
	Average	3.07	1.59
Conversion efficiency (%)	Minimum	12.05	10.49
	Maximum	21.67	22.44
	Average	13.55	17.17

panel temperature, conversion efficiency, flow rate and solar irradiance due to smog effect was compared with the data, 3 days before smog started (Table 2).

The average ambient temperature before smog was 29.30°C which decreased to 24.25°C due to the effect of smog. Similarly the average panel temperature before smog was 40.12°C which reduced to 31.27°C due to decrease in the ambient temperature during smog. Effect of smog was also clearly visible on solar irradiance and flow rate. Average solar irradiance before smog was 828 W/m² which was reduced to 393 W/m², i.e. by 52.53% due to smog layer accumulated near the panels. Average flow rate also reduced by 48.21% due to significant reduction in solar irradiance and array output. Reverse trend was found in case of conversion efficiency as average conversion efficiency increased before smog from 13.55–17.17% during smog.

This is because of higher panel temperature before smog which resulted in lower array output as compared to solar irradiance available. Moreover, the average conversion efficiency (17.17%) lies between optimum panel temperature ranges (12–32°C).

Effect of clouds: The cloud effect was evaluated on voltage, current, RPM, flow rate, ambient temperature and panel temperature on various days when clouds intercepted solar radiation for one and five hours.

Effect of clouds overcast for about one h on SPV system parameters: The cloud effect was evaluated on SPV system parameters on 12th September 2017, when clouds intercepted solar radiation between 2:00 pm to 3:00 pm. During the cloudy period, current decreased from 12 to 6 Amp resulting in lower array output (VI) which caused lowering of RPM of motor and subsequently flow rate decreased. Current, RPM and flow rate regained at 4:00 pm (Table 3). There was negligible effect on ambient temperature due to cloud overcast.

Effect of clouds overcast for about five h on SPV system parameters: The cloud effect was evaluated on SPV system parameters on 28th August 2017, when clouds intercepted solar radiation between 11:00 am to 3:00 pm (Table 4). During the cloudy period, current decreased firstly from 9 Amp to 7 Amp due to rainfall which resulted in stoppage of pump. Then current was again regained from 7 Amp to 10 Amp when rainfall stopped at 1:00 pm. At 2:00 pm clouds were again seen due to which current decreased from 10 Amp to 7 Amp and again regained from 7 Amp to 11 Amp when clouds were clear. Again under this situation it was seen there was negligible effect on ambient temperature.

This study concludes that the major factor which influences the performance of any SPV pumping system is the conversion efficiency and conversion efficiency is significantly affected by the panel temperature. So to reap maximum advantage it is essential to maintain low temperatures at the surface of the panels (12–32°C) especially during summers and similar weather conditions of the year. The range of optimum panel temperature should be between 12–32°C at which conversion efficiency will

Table 3 Effect of clouds overcast for about 1 h on SPV system parameter

Time	Solar Irradiance (W/m ²)	Voltage (V)	Current (I)	RPM	Flow rate (Lps)	Ambient Temperature (°C)	Panel Temperature (°C)	Cloud Overcast
08:15	508	587	8	1541	1.26	29.00	35.58	
09:00	699	575	11	2106	3.80	30.00	45.90	
10:00	783	568	11	2169	4.18	32.00	50.18	
11:00	807	553	12	2242	4.73	34.50	55.30	
12:00	815	549	12	2250	4.78	36.00	57.78	
01:00	822	552	12	2221	4.63	35.00	55.23	
02:00	866	545	12	2253	4.88	37.00	55.88	Cloudy
03:00	292	560	6	1849	2.61	36.00	51.20	Cloudy
04:00	718	541	9	1994	3.28	34.00	43.48	
05:15	410	564	8	1445	0	32.00	37.35	

Table 4 Effect of clouds overcast for about 5 h on SPV system parameter

Time	Solar irradiance (W/m ²)	Voltage (V)	Current (I)	RPM	Flow rate (Lps)	Ambient temperature (°C)	Panel temperature (°C)	Cloud Overcast
08:15	647	597	7	1438	0	29.00	32.68	
09:00	728	579	8	1757	2.18	31.00	42.53	
10:00	882	561	9	1893	2.85	31.50	47.48	
11:00	918	548	9	1948	3.03	33.00	50.78	Cloudy
12:00	226	585	7	1425	0	34.00	47.10	Rainfall
01:00	266	573	7	1439	0	36.00	47.90	Rainfall
02:00	1011	541	10	2011	3.34	37.00	49.63	Cloudy
03:00	272	582	7	1441	0	36.00	47.98	Rainfall
04:00	939	578	11	2203	4.32	36.00	45.40	
05:15	804	599	8	1469	0	32.00	41.53	

be maximum varying from 18.39–21.0%. The flow rate in summer, monsoon, post-monsoon and winter seasons varied from 0.72 Lps to 5.18 Lps, 0.39 Lps to 4.60 Lps, 0.37 Lps to 5.79 Lps and 0.81 Lps to 4.93 Lps, respectively. The average flow rate in summer, monsoon, post-monsoon and winter season was 3.0 Lps, 2.17 Lps, 3.44 Lps and 2.93 Lps, respectively. The conversion efficiency in summer, monsoon, post-monsoon and winter season varied from 9.27–21.71%, 8.09–22.94%, 10.67–22.96% and 10.49–22.96%, respectively. The average conversion efficiency in summer, monsoon, post-monsoon and winter season was 14.36, 15.13, 17.04 and 16.85%, respectively. During smog the average solar irradiance and flow rate decreased from 828 W/m² to 393 W/m² and 3.07 Lps to 1.59 Lps, respectively as compared with before smog conditions. The presence of clouds significantly affected/lowered down the current, RPM and flow rate but the temperature did not change much which reveals that temperature has minimum effect on the development of current and voltage in solar photovoltaic cells.

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