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Experimental Investigation of Effect of Environmental Variables on Performance of Solar Photovoltaic Module

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Abstract: *In the present study, experimental investigation of effect of environmental variables on performance of solar photovoltaic module has been conducted. The experiments were performed at 100 kW rooftop solar power plant and the research laboratory of Mechanical Engineering Department at Poornima University, Jaipur, India (Latitude: 26⁰55" and Longitude 75⁰46"). An experimental investigation was carried out to specifically evaluate the performance of 300W Polycrystalline Solar Photovoltaic (PV) module under various environmental factors such as dust, temperature, humidity, altitude, vegetation, ground type etc. The outcome of test results indicates that every variable has considerable amount of impact on the performance of solar photovoltaic module. This paper elaborates the investigation methodology, outcome under different set up conditions and the results have been discussed in this paper. It has been observed that various small measures related to environmental issues if handled efficiently can make a significant impact on improving the operational efficiency of solar PV plants of larger capacities.*

Keywords: Solar cells, PV efficiency, Dust, Humidity, Air velocity, Photovoltaic, Vegetation, Ground Type

1. INTRODUCTION

Energy is one of the most significant factor in the economic development of any country. With increase in an economic development of country also increases the energy consumption of that country. The world daily oil consumption in today's scenario is 85 million barrels of crude oil and it is expected that by the year 2025 this will increase to 123 million barrels per day. The 100kW solar photovoltaic (PV) system installed on the roof of the academic block of Poornima University, Jaipur serves as model for the installation of PV systems in institutional sector, which plays a major role in energy sustainability and security while solving the greenhouse gas emission problem of the nation. For diesel generators in developing countries like India, the solar photovoltaic (PV) systems are one of the most promising and cost-effective substitute. In India most of the people lives in rural and remote areas where either the grid is not present or electricity is not available all the time. In solar photovoltaic system, high solar radiation incident on solar photovoltaic module provide high electrical output but simultaneously it also increases the surface temperature of the solar module which results in decrease in the efficiency of the solar module. At STP conditions and type of material of solar cell, the electrical conversion efficiency of commercially available solar module is in the range of 7–15%. It has been found that with increase in 1 0C in surface temperature of solar photovoltaic module, there is decrease in efficiency by 0.5%. Various factors affect the performance of solar photovoltaic module which are discussed in this paper.

2. METHODOLOGY:

The experiments were carried out under the following conditions:

Location	Jaipur, Rajasthan, India
Meteorological Conditions	Latitude of 26.91ºN; Longitude of 75.78ºE
Month	July 2017 and August 2017
Time	9.00 a.m. to 4.00 p.m.

Various parameters were evaluated during the experiments such as solar intensity, wind velocity, ambient temperatures, relative humidity, open circuit voltage, short circuit current, power output, surface temperature of module, fill factor, etc. The parameters were measured in the month of July-August 2017 from 9.00 a.m. in the morning to 4.00 p.m. in the evening.

Figure 1. 300W solar module for experimental set up

Table 1. Specifications of 300W solar module employed for the experimental study

Solar PV Module Specification	
Model	ELDORA 300
Make	300 W
Open Circuit Voltage	45.1 V
Short Circuit Current	8.74 A
Maximum Current	8.05 A
Maximum Voltage	37.28 V
Efficiency	15.63 %
Fill Factor	76.13%
NOCT	45 0 C

2.1. Specification of plant

The rooftop solar PV plant installed at Poornima University, Jaipur is of 100 kW_P capacity. From the site of MNRE, India it was found that Rajasthan has average solar irradiation of 1266.52 W/m^2 and average sunshine hours is 5.5 hours. The plant will produce approximately 450 kWh per day and approximately 1,50,000 kWh per annum.

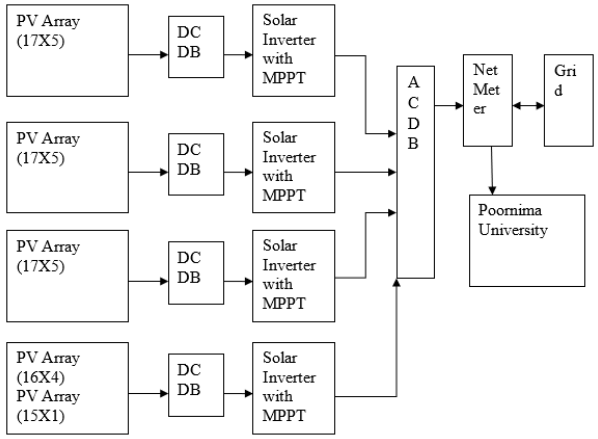

Figure 2: Block Diagram of 100 kW_P rooftop solar power plant at Poornima University

Figure 3: 100 kW_P rooftop solar power plant at Poornima University

2.2 Performance Evaluation

Photo Electric conversion efficiency, $\eta e = \frac{Im\ Vm}{GA}$ (1)

According to first law of thermodynamics, the exergy equation for an open system under steady state assumption, can be written as

$$E_{in} = E_{out} \quad (2)$$

General equation for the exergy balance:

$$EX_{in} - E_{out} = E_{loss} \quad (3)$$

A solar cell's energy conversion efficiency is the percentage of power converted and collected, when a solar cell is connected to an electrical circuit. Energy efficiency of the solar PV can be defined as the ratio of power output

to energy input of the solar PV. The output power and energy efficiency of the PV system, however, fluctuates depending on solar insolation and surface temperature. The energy conversion efficiency of the solar PV (ηenergy) is calculated from the following equation: [1-2].
The current-voltage characteristics of the electric circuit of solar cell can be described by the following simplified equation

$$I = I_1 - I_0 \times \exp^{\left[\frac{q\times(V-IR_s)}{A\times K\times T}\right]} \quad (4)$$

The electric power output of PV is:

$$Pel = I \times V \quad (5)$$

The maximum power output is given by:

$$Pmax = VOC \times ISC \times FF \quad (6)$$
$$Pmax = Vmp \times Imp$$

3. RESULTS AND DISCUSSION:

3.1. Performance of 300W Solar Photovoltaic Module

The performance of 300W Solar Photovoltaic Module was evaluated on July 15, 2017. Various factors were measured such as solar radiation, ambient temperature, surface temperature of photovoltaic module, open circuit voltage, short circuit current and electrical efficiency. It has been found that with increase in surface temperature of photovoltaic module the efficiency decreases.

Table 2: Performance of 300W Solar Photovoltaic Module

Date: July 15, 2017					
Time	**Global Radiation (W/m²)**	**Ambient Temperature (°C)**	**Surface Temperature of Solar PV (°C)**	**Power (W)**	**Electrical Efficiency of PV system (%)**
9:00	269	32.3	37.5	75.988	14.41977
10:00	535	33.7	40.2	122.45	11.68344
11:00	722	34.4	41.5	151.13	10.68511
12:00	877	34.7	44.3	175.39	10.20871
13:00	997	34.9	46.8	189.01	9.677322
14:00	990	35.8	45.2	187.03	9.643655
15:00	881	36.4	44.1	177.88	10.30663

3.2. Effect of Wind Velocity and Altitude

The tests were conducted consist of three Solar photovoltaic modules installed on the ground and three Solar photovoltaic modules installed at the altitude of about 150 feet i.e the roof of University. The performance of both the test set-up was evaluated and various parameters were noted. It has been found that with increase in altitude the power generation capacity of module increases. It is because of high wind velocity at high altitude than ground. This results in good convective heat transfer which reduces the surface temperature of module and increases the efficiency.

Table 3: Effect of Wind Velocity and Altitude on Performance of Solar Photovoltaic Module

Date: July 21, 2017. Time: 11:00, University Ground					
Ambient Temperature (°C)	**Humidity (%)**	**Wind Velocity (km/h)**	**Solar Radiation (W/m²)**	**Power Output of Solar PV Panel (W)**	**Efficiency of Solar PV Panel (%)**
34.4	30	3	722	133.86	9.46
34.4	30	3	722	134.33	9.49
34.4	30	3	722	138.79	9.81
Date: July 21, 2017. Time: 13:00, University Ground					
Ambient Temperature (°C)	**Humidity (%)**	**Wind Velocity (km/h)**	**Solar Radiation (W/m²)**	**Power Output of Solar PV Panel (W)**	**Efficiency of Solar PV Panel (%)**
34.9	28	6.5	997	178.76	9.15
34.9	28	6.5	997	171.91	8.80
34.9	28	6.5	997	175.49	8.98
Date: July 21, 2017. Time: 11:00, Altitude – 150 feet (Roof of University)					
Ambient Temperature (°C)	**Humidity (%)**	**Wind Velocity (km/h)**	**Solar Radiation (W/m²)**	**Power Output of Solar PV Panel (W)**	**Efficiency of Solar PV Panel (%)**
34.4	30	7	722	151.13	10.68
34.4	30	7	722	148.91	10.52
34.4	30	7	722	150.10	10.61
Date: July 21, 2017. Time: 13:00, Altitude – 150 feet (Roof of University)					
Ambient Temperature (°C)	**Humidity (%)**	**Wind Velocity (km/h)**	**Solar Radiation (W/m²)**	**Power Output of Solar PV Panel (W)**	**Efficiency of Solar PV Panel (%)**
34.9	28	11	997	189.01	9.67
34.9	28	11	997	189.72	9.71
34.9	28	11	997	189.43	9.69

Table 4: Percentage Accession in power generation due to Wind Velocity and Altitude

Date: July 21, 2017. Time: 11:00		
Power generate at University Ground in Watts (P1)	**Power generate at University Roof Watts (P2)**	**Percentage Accession in power generation (%)**
133.86	151.13	12.90
134.33	148.91	10.85
138.79	150.10	8.14
Date: July 21, 2017. Time: 13:00		
Power generate at University Ground in Watts (P1)	**Power generate at University Roof Watts (P2)**	**Percentage Accession in power generation (%)**
178.76	189.01	5.73
171.91	189.72	10.36
175.49	189.43	7.94

3.3. Effect of Type of Ground Surface on Performance of Solar Photovoltaic Module

The tests were conducted by keeping three 300W solar photovoltaic module in three different type of ground surfaces i.e. Barren Land, Grass Land and in water tray. The performance of modules was evaluated and various parameters were noted. It was found that module in water tray is having highest efficiency of 13.53% and module in barren land is having lowest efficiency of 9.50%. This is because of the effect of vegetation on solar photovoltaic module. From the table 5, it has been noted that the modules in grass land and water tray are having lower surface temperature than that of module in barren land. The water and grass reduces the surrounding temperature which reduces the surface temperature of solar module hence increases the efficiency of solar module.

Table 5: Effect of Type of Ground Surface on Performance of Solar Photovoltaic Module

Date: July 25, 2017. Time: 11:00					
Ground Type	**Solar Radiation (W/m^2)**	**Ambient Temperature (^oC)**	**Power in Watts**	**Efficiency in %**	**Module Surface Temperature (^oC)**
Ground (Barren)	722	35.70	152.12	10.75	43.50
Ground (Grass)	722	35.70	173.43	12.26	40.90
Water Tray	722	35.70	191.55	13.53	37.30
Date: July 25, 2017. Time: 12:00					
Ground Type	**Solar Radiation (W/m^2)**	**Ambient Temperature (^oC)**	**Power in Watts**	**Efficiency in %**	**Module Surface Temperature (^oC)**
Ground (Barren)	912	36.50	175.39	9.81	45.80
Ground (Grass)	912	36.50	195.10	10.92	42.70
Water Tray	912	36.50	210.23	11.77	39.60
Date: July 25, 2017. Time: 13:00					
Ground Type	**Solar Radiation (W/m^2)**	**Ambient Temperature (^oC)**	**Power in Watts**	**Efficiency in %**	**Module Surface Temperature (^oC)**
Ground (Barren)	1015	37.30	189.01	9.50	48.80
Ground (Grass)	1015	37.30	208.55	10.48	46.40
Water Tray	1015	37.30	222.89	11.21	42.10

3.4. Effect of Dust on the Performance of Solar Photovoltaic Module

The tests were conducted using two panels each of 300W capacity. One was cleaned everyday and one was kept as it is in the open environment. The performance of both the solar panels were evaluated after 15th and 30th day and various parameters were noted. From table 6 it can be seen that, there is drop in power output of dirty solar panel compared to cleaned solar panel. The dust particles obstruct sunlight entering in solar cell and act as shadow. The dust on solar panel has considerable effect on performance of solar cell.

Table 6: Effect of Dust on the Performance of Solar Photovoltaic Module

Date: August 12, 2017. (15th Day)							
Time	**Global Radiation (W/m^2)**	**Ambient Temperature (^oC)**	**Power of dirty PV (P1) in Watts**	**Efficiency of dirty PV (%)**	**Power of dirty PV (P1) in Watts**	**Efficiency of dirty PV (%)**	**(P2-P1) P2 (%)**
9:00	335	31.5	72.78	11.09	75.18	11.45	3.19
11:00	777	32.3	150.58	9.89	158.12	10.38	4.77
13:00	1010	34.7	178.87	9.04	191.12	9.66	6.41
15:00	851	35.4	159.22	9.55	171.40	10.28	7.11

Date: August 29, 2017. (30th Day)							
Time	Global Radiation (W/m²)	Ambient Temperature (°C)	Power of dirty PV (P1) in Watts	Efficiency of dirty PV (%)	Power of dirty PV (P1) in Watts	Efficiency of dirty PV (%)	(P2 - P1) P2 (%)
9:00	369	32.3	73.18	10.12	79.98	11.06	8.51
11:00	749	34.9	141.31	9.63	155.49	10.60	9.12
13:00	997	35.8	169.98	8.70	192.30	9.48	11.61
15:00	875	36.2	149.46	8.71	173.56	10.12	13.89

4. CONCLUSION

This study was carried out in Poornima University, Jaipur to determine the effect of various environmental factors on performance of 300W solar photovoltaic module. The effect of various environmental factors on performance of solar module were investigated and it has been concluded that:

1. Altitude and wind velocity plays an important role in the performance of solar photovoltaic module. With increase in wind velocity the efficiency of solar module increases. Similarly, with increase in altitude the performance of solar module improves and the power output increases. Through this we can conclude that rooftop solar plants are having better performance.

2. Vegetation and type of land also impact the performance of solar photovoltaic. The study was conducted on three types of land and it has been found the solar module in water tray is having highest efficiency and module in barren land is having lowest efficiency. Through this we can conclude that solar power plant on water bodies will have better performance. We should also plant grass on ground where large size solar plants are installed. This improves the efficiency of overall plant.

3. Effect of dust also plays an important role in performance of solar photovoltaic module. The dust obstructs the sunlight by acting as shadow and reduces power output by 13.89%. Through this study it is clear that we should prepare clearing plan of solar modules in solar power plants. We should clean the solar modules in every ten days to maintain the performance of plan.

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