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Effect of Dust Accumulation on Efficiency of Solar Panels in Clement Town Region (Dehradun) India: An Empirical Study

Arun Pratap Singh Rathod[1*], Pawan K. Mishra[2] and Abhilasha Mishra[1*]

[1]Graphic Era Deemed to be University, Dehradun, Uttarakhand, India
[2]G.L.A. University, Mathura, Uttar Pradesh, India

[*]Correspondence to:
Arun Pratap Singh Rathod
Graphic Era Deemed to be University,
Dehradun, Uttarakhand, India.
E-mail: major.rathod@gmail.com

Abhilasha Mishra
Graphic Era Deemed to be University,
Dehradun, Uttarakhand, India.
E-mail: abhi1680@gmail.com

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Abstract

The solar energy is considered to be the ultimate source of energy and primary source of renewable energy on the Earth. From the average solar energy of 342 W/m^2 available in the upper atmosphere only 239 W/m^2 reaches earth surface and rest is radiated back to space. Harvesting solar energy through semiconductor based solar cells is affected by several factors and dust accumulation is one such factor. Dust accumulation creates a coating over the panel that limits the reception of sunlight and increases the temperature inside the solar panels. As a result of dust coating the number of incident photons reaching the solar cells decreased substantially, resulting in diminished current output and lower efficiency. Further, due to insulating effect of the dust layer, heat from the panel does not radiate effectively and induces a random movement in the charge carriers inside solar cells, depreciating overall power output of the solar cell. With increasing pollution, the amount of dust particles in the atmosphere is increasing exponentially. Consequently, the efficiency of solar cells is being adversely affected universally, offsetting the positive effects of technological improvements in designs and manufacturing of solar cells. Over a period of 45 days an average drop of 22.5% is observed in the efficiency of polysilicon solar panels in clement town region in Dehradun. Further it has been found in the study that accumulation of dust particles offsets the advantages of higher altitude, greater irradiation, and lower temperature which are considered favorable for harnessing solar energy.

Keywords

Dust accumulation, Efficiency, Polysilicon, Solar cell, Solar energy

Introduction

Solar energy is the most abundant source of energy on Earth. Solar cells are used to harness solar energy by converting it into electrical energy. The SPPs used for generating electricity from sunlight are comprised of an array of solar panels. Depending on the nature of SPP i.e., whether it is grid connected or standalone system, additional components like inverter, battery, or charge controller may also be required. Depreciation in the performance of solar panel in terms of efficiency over time is highly undesirable, considering high installation costs of SPPs. Average operating lifespan of solar panels is reported to be 25 years [1]. A degradation of 4.7% in the efficiency of solar panels, has been reported by Hottel and Woertz due to dust accumulation on the panels [2]. While Salim et al. reported that accumulation of dust causes 32% depreciation in performance of SPP located in Riyadh [3].

The experiment conducted by Google found that the effect of dust accumulation on SPP's efficiency is more profound in flat panels than tilted panels [4]. In a comparative study in Palo Alto, California, it was found that the accumulation

of dust on solar panels depreciates current generation significantly when compared to clean solar panel [5]. In India, an 8% reduction in transmittance is reported in glass plated solar panels tilted at 45 degrees due to accumulation of dust after 10 days in Roorkee [6]. Reduction in efficiency, transmittance, and output current due to dust accumulation is a universal phenomenon [7-9].

Previous studies reported and highlighted the effect of dust accumulation on the performance of SPPs but fail to explain the material level events behind it. In this research article an experiment is conducted to ascertain the effect of deposition of dust on solar panels in Clement town region, Dehradun, India. Also, the consequent events occurring inside the semiconductor material are also explained to develop a better understanding of the problem statement and facilitate informed and targeted solutions.

Materials and Methods

Mathematical analysis of deterioration in panel efficiency due to dust accumulation

Accumulation of dust over solar panels causes reduction in received solar radiation and increment in temperature of solar panel, as shown in figure 1. The performance of semiconductor based solar cells is temperature sensitive. Increment in temperature decreases energy bandgap of semiconductor materials and affects the various performance parameters of the solar cell. Consequently, a lower amount of external energy is required to free the valence electrons. Among different parameters the open circuit voltage (V_{OC}) is greatly affected by the temperature variations as reduction in temperature results in decrement in open circuit voltage (V_{OC}) and vice versa.

This is due to the dark saturation current of the photodiode (leakage current of diode in the absence of the light) shows increment with increase in temperature. Dark saturation current (I_o) equation of PN Junction diode is given by following equations [10, 11]:

$$I_o = qA\frac{Dn_i^2}{LN_D} \tag{1}$$

Where, q is electron charge, A is area, D is diffusing ability of minority charge carriers in silicon as a function of total doping, diffusion length of minority charge carriers is denoted by L, N_D is doping concentration, and n_i is intrinsic carrier concentration.

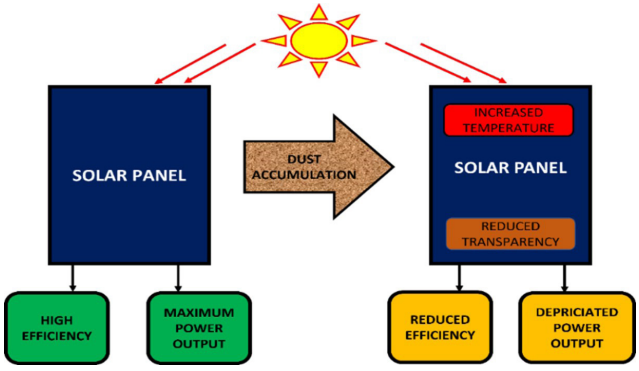


Figure 1: Effects of dust accumulation on the performance of solar panels.

The intrinsic carrier concentration is dependent on the energy band gap of the semiconductor material. Consequently, with rise in temperature the energy band gap inside silicon reduces and higher concentrations of charge carriers are produced inside the intrinsic semiconductor material [12]. Concentration of intrinsic charge carriers is given by:

$$n_i^2 = 4\left(\frac{2\pi kT}{h^2}\right)^3 (m_e m_h)^{3/2} \exp\left(-\frac{E_{G0}}{kT}\right) \tag{2}$$

$$n_i^2 = BT^3 \exp\left(-\frac{E_{G0}}{kT}\right) \tag{3}$$

Where, T stands for temperature, k and h are constants, m_h and m_e are effective masses of holes and electrons respectively, E_{GO} denotes the linear band gap generalised to absolute zero, temperature independent constant is denoted by B.

Substituting values in Eq. 1 from Eq. 3

$$I_o = qA\frac{D}{LN_D} BT^3 \exp\left(-\frac{E_{G0}}{kT}\right) \tag{4}$$

$$V_{OC} = \frac{kT}{q}\ln\left(\frac{I_{SC}}{I_O}\right) \tag{5}$$

Where, B' represents constant independent of temperature, γ denotes temperature dependent constant [13-16].

To determine the relationship between dark saturation current (I_o) and open circuit voltage (V_{OC}) is given by:

$$V_{OC} = \frac{kT}{q}\ln\left(\frac{I_{SC}}{I_O}\right) \tag{6}$$

$$V_{OC} = \frac{kT}{q}\left[\ln I_{SC} - \ln I_O\right] \tag{7}$$

$$V_{OC} = \frac{kT}{q}\ln I_{SC} - \frac{kT}{q}\ln\left[B'T^{\lambda} exp\left(\frac{qV_{Go}}{kT}\right)\right] \tag{8}$$

$$V_{OC} = \frac{kT}{q}\left(\ln I_{SC} - \ln B' - \gamma \ln T + \frac{qV_{Go}}{kT}\right) \tag{9}$$

Since $E_{GO} = qV_{GO}$, and according to assumption dV_{OC}/dT is dependent on dI_{SC}/dT, then dV_{OC}/dT is given by:

$$\frac{dV_{OC}}{dT} = \frac{V_{OC} - V_{GO}}{T} - \gamma\frac{k}{q} \tag{10}$$

As shown in Eq. 10, temperature is inversely related to open circuit voltage (V_{OC}) of semiconductor based solar cells. It

means that with rise in temperature inside solar cell, reduction in open circuit voltage is inevitable. Generally, in case of silicon the equivalent value of E_{GO} is 1.2, and by taking 3 as the equivalent value of γ and by placing these values in Eq. 10 the change in open circuit voltage with respect to temperature is determined to be -2.2 mV/°C. This means that there is a drop of 2.2 mV in open circuit voltage of a silicon based solar cell for per degree Celsius rise in the temperature.

$$P_{max} = V_{OC} I_{SC} FF \tag{11}$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}} \tag{12}$$

Where, open circuit voltage is V_{OC}, and short circuit current is I_{SC}, FF is fill factor, P_{max} and P_{in} denotes maximum power output of solar cell and incident input power received by solar cell, respectively. Efficiency of the solar cell is represented by η [17].

It is clearly inferred from Eq. 12 that open circuit voltage (V_{OC}) is directly proportional to the efficiency of the solar cell. Therefore, any decrement the open circuit voltage of the solar cell results in the decline of the efficiency of the solar and vice versa. Also, increasing temperature generate smaller number of additional electron hole pairs in the semiconductor by reducing the energy band gap. This results in minor increment in short circuit current (I_{SC}). But effect of this phenomenon is very limited and has no significant contribution to the overall efficiency of the solar cell. Hence the high temperatures in silicon solar cells result in depreciation in the performance of the solar cell by degrading the maximum power output and the efficiency of the solar cells.

The tiny dust particles suspended in the air tend to settle of surfaces they encounter. Since the solar panels are installed outdoors, they remain prone to dust accumulation. When dust settles on solar panels it starts depreciating the transparency of the outer glass cover of the solar panel. Over a period of time the transparent outer glass tends to become opaque and amount of solar radiation actually reaching the solar cell diminishes gradually. As a result, lower amount of energy is transferred by incident photons to the electrons inside the semiconductor material. Hence lower number of electron-hole pairs are generated. Since the short circuit current (I_{SC}) is directly dependent on the total number of charge carriers inside semiconductor, it starts diminishing. Consequently, the overall efficiency of the solar cell also degrades as efficiency of a solar cell is directly proportional to short circuit current as shown in Eq. 12. Due to this SPPs located at higher altitudes, receiving excellent insolation fail to produce greater electricity. Also due to dust accumulation higher efficiency solar cells with better materials and superior architecture are found to be incapable of generating expected results.

Experimental setup

Dust accumulation poses a serious issue to the operational efficiency of SPP. To identify the problems generated by dust accumulation inside the solar panels an experimental setup was installed in the clement town region of Dehradun district, India. The latitudinal and longitudinal position of the installed setup was 30°16'02.3"N 77°59'46.5"E. The setup was comprised of two roof top polysilicon solar power plants of 1 kW each viz. SPP A and SPP B installed in the premises of Graphic Era Deemed to be university Dehradun. The SPPs were connected to inverters through which the generated current is stored in batteries. Also loads were attached to the SPPs to regularly discharge the batteries and allow the storage of electricity produced by SPPs uninterruptedly. Two current and voltage measuring devices viz. I-V checker A and I-V checker B were also connected to the SPP A and SPP B respectively to measure the performance parameters like open circuit voltage (V_{OC}), short circuit current (I_{SC}), efficiency, fill factor (ff) etc., as shown in figure 2.

When sunlight carrying photons falls on SPP A and SPP B, the electrons inside the polysilicon based solar cells energize and jump from valence band to conduction band and electric-

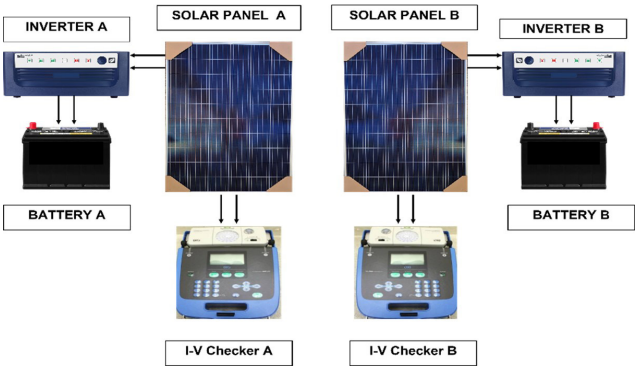


Figure 2: Experimental setup employed for studying effects of dust accumulation on solar cells.

ity is generated. The I-V checkers attached to the respective solar power plants measure the data and store the relevant performance parameters at regular intervals set by the user. The experiment is conducted over a period of 45 days in the month of March and April 2022. SPP A is left uncleaned for the whole duration whereas SPP B is cleaned every fourth day. This is done to study the effect of the accumulation of dust layer on solar power plants and variation in performance over the period of 45 days.

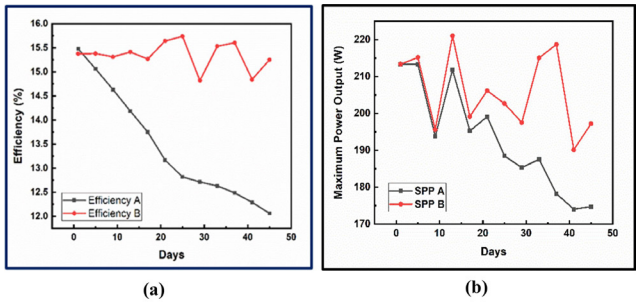
Results and Discussion

The performance of SPP A and SPP B is observed for a period of 45 days. During this period the average solar irradiation was recorded as 1107.44 W/m² and average atmospheric temperature was 36.14 °C. It was found that the efficiency of both SPP A and SPP B was almost identical initially. As the concentration of dust layer enhanced over SPP A, its performance depreciated linearly for the next 20 days. The reduction in efficiency continued but the rate of depreciation was gradual for the next 25 days. Overall, an approximated 22.5% reduction in efficiency was recorded for SPP A and efficiency of SPP B varied between 0 to 3.2% from the initial reading during the same time period under same atmospheric conditions as shown in figure 3a.

As discussed in previous sections that reduction in the efficiency of solar cells is related to the open circuit voltage

(V_{OC}) and short circuit current (I_{SC}) generated inside the solar panel. The data collected over the period of 45 days from SPP A and SPP B through I-V Checker A and I-V Checker B respectively was analyzed. The power output of SPP A decreased from 213.34 W to 174.71 W over the period of 45 days, while power output of SPP B varied between 213.33 W and 197.20 W for the same period as shown in figure 3b. Initially, for ambient temperature of 38 °C (approx.) the recorded panel temperature of SPP A was 45 °C (approx.) as elucidated in figure 4a. After 45 days for ambient temperature of 37 °C (approx.) the panel temperature was 54 °C (approx.). Hence due to dust accumulation the temperature difference increased from 7 °C to 17 °C in 45 days. On the contrary, it is clear from figure 4a that the panel temperature of SPP B maintains a stable difference of 7 °C with ambient temperature for the same time duration and under same weather conditions as for SPP A with variation of ±1 °C.

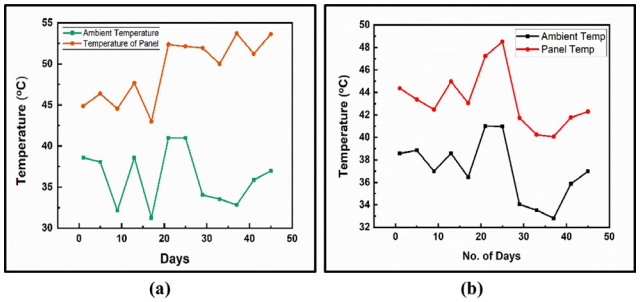
Due to dust concentration over SPP A the penetration of photons inside solar cells was restricted to some extent, due to



(a) (b)

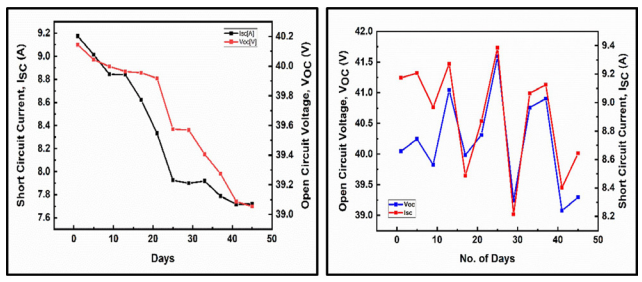
Figure 3: (a) Comparison of efficiency of SPP A and SPP B over the period of 45 days. **(b)** Comparison of power output of SPP A and SPP B over the period of 45 days.

which lower number of charge carriers were able to jump from the valence band to conduction band. Consequently, current generation inside solar cells of SPP A was affected negatively and its magnitude depreciated continuously along with open circuit voltage (V_{OC}) for the duration of 45 days as shown in figure 5a. On the other hand, no such declining trend is observed in SPP B as transparency is maintained through regular cleaning of the solar panels. Thus, in SPP B the open channel voltage and short circuit current does not decline over the same time duration and variations in their magnitudes are attributed to fluctuations in the quantum of isolation received by the panels. The variation trend of short circuit current (I_{SC})



(a) (b)

Figure 4: (a) Comparison of ambient temperature with panel temperature of SPP A over the period of 45 days. **(b)** Comparison of ambient temperature with panel temperature of SPP B over the period of 45 days.



(a) (b)

Figure 5: (a) Graphical representation of short circuit current and open circuit voltage levels produced by SPP A over the period of 45 days. **(b)** Graphical representation of short circuit current and open circuit voltage levels produced by SPP B over the period of 45 days.

and open circuit voltage (V_{OC}) in SPP B is displayed in figure 5b.

The data record from SPP A and SPP B is summarized in table 1. A clear diminishing trend in the efficiency level of solar cells in SPP A is observed with increment in time, whereas for same time duration no such decreasing trend is observed in SPP B. Similarly constant deduction in values of short circuit current (I_{SC}) and open circuit voltage (V_{OC}) of SPP A with time could attributed to dust accumulation, because under same atmospheric conditions the regularly cleaned SPP B does not show such decrement in short circuit current (I_{SC}) and open circuit voltage (V_{OC}). The variations in the different parameters of SPP B are a result of fluctuations in atmospheric conditions and unlike SPP A there is no continuous decremental trend in the performance parameters.

Conclusion

The results of the experiment conducted conclusively prove the dust accumulation has a detrimental effect on the performance of solar panels or solar cells. It increases the

Table 1: Performance summary of SPP A and SPP B over the period of 45 days.

Days	Solar Power Plant A			Solar Power Plant B		
	I_{SC} (A)	V_{OC} (B)	Efficiency (%)	I_{SC} (A)	V_{OC} (B)	Efficiency (%)
1	9.173	40.144	15.478	9.173	40.044	15.376
5	9.013	40.044	15.062	9.207	40.244	15.379
9	8.843	39.997	14.632	8.968	39.826	15.312
13	8.840	39.964	14.185	9.273	41.044	15.412
17	8.621	39.955	13.749	8.486	39.984	15.268
21	8.332	39.917	13.167	8.871	40.312	15.642
25	7.926	39.575	12.819	9.385	41.592	15.738
29	7.899	39.569	12.711	8.215	39.240	14.820
33	7.918	39.407	12.631	9.065	40.758	15.534
37	7.788	39.275	12.486	9.126	40.905	15.605
41	7.716	39.087	12.297	8.402	39.075	14.846
45	7.718	39.053	12.060	8.644	39.294	15.249

temperature inside solar panels and reduces their efficiency. Also, it has a negative impact on short circuit current (I_{SC}) and open circuit voltage (V_{OC}) and power output of the solar cell. A depreciation of approximately 22.5% is observed in the efficiency of a solar panels (SPP A) with dust accumulation layer over a period of 45 days. Whereas the solar panels (SPP B) which were regularly cleaned showed only a variation of 0 to 3.2% for the same weather conditions and time period without any decreasing trend. Hence the dust accumulation on solar panels should be avoided for optimum and efficient performance.

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Conflict of Interest

Authors do not have any conflict of interests.

Credit Author Statement

All the authors contributed equally. All the authors read and approved the manuscript.

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