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An Assessment of the Impact of Accumulated Dust on Efficiency and Performance Output of Solar Photovoltaic Panels

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ABSTRACT

Part of the major causes of low performance and output of solar photovoltaic (PV) systems is dust accumulation on the panel. The radiation getting to the solar cells of the panel can be decreased due to the accumulation of dust on the surface of the solar PV panel. Dust decreases the amount of radiation on solar cells of the panel, and also reduces the performance output of the solar PV panel. The environment is one of the contributing parameters which directly affect the photovoltaic performance. In this research work, the influence of dust, on the efficiency and performance output of solar PV panels is investigated to determine the efficiency of the solar PV panel, determine the energy power output of the solar PV system. Three identical panels are used to measure voltage, current and temperature. The result obtained showed that the mean efficiency for the clean panel is 14.98%, the mean efficiency for panel with artificial dust is 11.19% and that of the panel with natural dust is 13.25%. The mean power P_{max} for the clean panel is 245.04 W, P_{max} for panel with artificial dust is 183.20 W and P_{max} for panel with natural dust is 216.86 W. This research shows the correlation between dust accumulation and reduced maximum power output due to the drop in both voltage and current values for the panel with dust.

Keywords:
Dust accumulation,
Solar photovoltaic panel,
Solar PV efficiency,
Panel performance.

INTRODUCTION

A drop in the efficiency of a solar PV panel throughout its life cycle is not desired, since the capital cost for the system is quite high. PV cells can normally last for about 25 years, and it takes approximately up to six years (Kannan et al., 2016) for the solar PV module to generate the equivalent amount of energy consumed in its manufacturing processes. The current and power output of the solar photovoltaic panel is proportional to the sunlight radiated on it. This means that the power output and efficiency of solar PV panel is dependent on the weather condition, time and the location of installation of the solar system. Consideration of the site of installation brings about installing a solar panel in a place where it will be able to capture enough sunlight (Eric, 2010). When sunlight radiates on the surface of the panel it is being absorbed, reflected or transmitted mainly transforming the energy of incident photons into electricity and the electrons is allowed to move across the crystal based on the principle of conservation of momentum and energy. This phenomenon is called photovoltaic effect (Mekhilef et al., 2012).

Hottel and Woertz (2012) were amongst the pioneers investigating the impact of dust on solar systems. They recorded a maximum degradation in collector performance of 4.7%, with an average loss in incident solar radiation being less than 1%. An experiment to investigate the effect of aeolian dust deposition on photovoltaic solar cells by Dirk Goosen et. al (2019) showed that the deposition of fine aeolian dust particles on the glazing of PV cells significantly affected the performance of such cells. The experiment was conducted to investigate the effect of wind velocity and airborne dust concentration on the drop of PV cell performance caused by dust accumulation. Photovoltaic modules (PV modules) are made up of multiple layers, including a protective cover, an anti-reflective coating, and a cell encapsulation layer, to protect the cells from environmental damage and ensure maximum energy production. The cells are usually made of silicon, and can be either monocrystalline, polycrystalline, or thin-film (Shanmugam *et al.*, 2020).

Dharmadasa state that once any of these four steps are omitted, the device will show low photovoltaic energy conversion or the photovoltaic activity will be zero. In

other for a photovoltaic energy conversion to take place effectively, the process must undergo four important steps together simultaneously. These steps are:

i. Electrons and hole pairs charge carriers must be created principally by breaking the bond in between the atoms.
ii. Before recombination must take place, they will be separation of oppositely free.
iii. Suitable material must be used for the photovoltaic system for easy absorption of photons.
iv. They must be movement of charge carriers through electric contacts that will pass through an external circuit to generate current (Dharmadasa, I.M. 2013).

Dust is commonly used to describe minute solid particles and materials with diameter less than 500 µm (Athar et al., 2017), that can be suspended in the air. It can originate from various sources, including soil, pollen, human activities, or industrial processes. The characteristics of dust settlement on solar PV system are dictated by two primary factors that influence each other namely; the property of the dust and the local surrounding. The location of solar panels is important when deciding on the development of a photovoltaic solar system (Bruendlinger et al., 2006). It is very clear that solar panels should be placed in such a way as to absorb solar radiation during the time when the sun is at its highest as shading supersedes this when it comes to dominance (Mahammad et al., 2013). Shadow effects solar panel performance considerably (Ramaprabha et al., 2010). Partial shadow or full shadow both affect the amount of solar radiation received by cells. Depending on the area of the cell that is shaded, the power-producing capacity of the cell will go down (Patel et al., 2008). Hence there will be a drop in the amount of energy output of the Solar PV when accumulated dust is present on the surface of the panel.

Effect of Accumulated Dust

Dust consists of tiny solid particles carried by air currents. These particles are formed by disintegration which is a process of fracturing the solids into small pieces through grinding, crushing, or impact among other ways. Dust is covered on the solar panel naturally. The layer of the dust on the solar panel increasing with the time respectively. It also acts as a barrier between solar panel and sun rays. There are two primary ways that dust affects the photovoltaic panels. First, dust settles directly on the solar photovoltaic panels, blocking the cells from the sun rays. The tracing sensor may be covered by dust, inhibiting the panels from following the sun direction (Nguyen and Sagar, 2009). The value of short circuit current, power decrease with respect the amount of dust on the solar panel.

The effect of dust's size also gives significant impact on the performance of solar PV panel system. Mani et al., (2010) was done the experiment on the effect of dust's size on the performance of solar PV panel system. The experiment was entirely simulated with artificial dusts which were limestone, cement and carbon particulates under constant halogen lamps. It was reported that fine carbon particulates of 5 mm in diameter was found to have the most deteriorating effect on the PV efficiency. The study also found the impact of finer particles to have a greater impact than coarser particles on PV performance for the same dust type. In addition, the same experiment also has been conducted by the different author, Sulaiman et al. (2011). Two different size of artificial dusts were used which were mud and talcum. From the result, it showed that talcum powder had lower power output generated as compared with the mud dust**.** In general, both researchers showed the same result for the impact of dust size on the performance of PV panel system.

MATERIALS AND METHODS

The experimental setup was setup to evaluate the impact of accumulated dust on efficiency and performance output of solar photovoltaic panels. Three 250W monocrystalline solar modules were used in the experiment to determine the open circuit voltage (Voc) and the short circuit current (Isc) of the three monocrystalline solar panels. One of the solar panel was kept in an outdoor environment for some weeks to achieve some amount of dust on the solar panel. For the measurements of output voltage and current, a digital multimeter were used and the experiments were conducted from 9:00am to 5:00pm, the collected data were recorded every two hours for a day.

Table 1: Specifications for the solar PV module

Model	**TMS-250PC05A.082**
Maximum Power ($\mathbf{P_{max}}$)	250W
Maximum Power Voltage ($\mathbf{V_{mp}}$))	30.3V
Maximum Power Current ($\mathbf{I_{mp}}$))	8.27A
Smart Voltage Output (Voc*)	33.4V
Maximum Current (Im)	9.5A
Maximum System Voltage	DC1000V
Maximum Series Fuse	15A
Module Application	Class A

Maximum power

Maximum power is calculated using the formula

$P_{max} = I_{max} \times V_{max}$ (1)

Where: P_{max} = Maximum Power, I_{mp} = Maximum Power Current , V_{mp} = Maximum Power Voltage (Mahnoor et al., 2023).

The efficiency of the panel

The efficiency of the PV modules is calculated by

Efficiency $(\eta) = \frac{\frac{P_{max}}{Area}}{G} \times 100\%$ (2)

where: P_{max} = Maximum Power, Area = length x width of the solar panel (m^2), G =1000 = Standard Test Condition (**STC**) irradiance (W/ m^2) (Mahnoor et al., 2023).

Percentage reduction

The percentage module's reduction is calculated by

$\eta(\%\ reduction) = \frac{\eta_{clean} - \eta_{dirty}}{\eta_{clean}}$ (3)

Where: $\eta clean$ = Efficiency of the clean module, $\eta dirty$ = Efficiency of the dirty module (Mahnoor et al., 2023).

RESULTS AND DISCUSSION

The clean panel consistently produced higher voltage, current and power output compared to the panels with dust on the surface as shown in the tables below.

Table 2: Result of the experiment for the clean solar panel

Time	Temperature (°C)	V_{mp} (V)	I_{mp} (A)	P_{max} (W)
9: 00am	36	30.3	7.2	218.16
11: 00am	41	33.2	7.6	252.32
01: 00pm	43	33.3	7.7	256.41
03: 00pm	43	33.3	7.6	253.08
05: 00pm	40	32.7	7.5	245.25

Table 3: Result of the experiment for panel with artificial dust

Time	Temperature (°C)	V_{mp} (V)	I_{mp} (A)	P_{max} (W)
9: 00am	36	25.7	5.9	151.63
11: 00am	41	27.1	6.1	165.31
01: 00pm	43	29.5	6.7	197.65
03: 00pm	43	30.2	6.9	208.38
05: 00pm	40	29.7	6.5	193.05

Table 4: Result of the experiment for the solar panel with natural dust

Time	Temperature (°C)	V_{mp} (V)	I_{mp} (A)	P_{max} (W)
9: 00am	36	27.3	6.4	182.91
11: 00am	41	29.7	6.8	224.64
01: 00pm	43	30.3	7.1	228.49
03: 00pm	43	31.9	7.3	234.75
05: 00pm	40	30.5	7.0	213.50

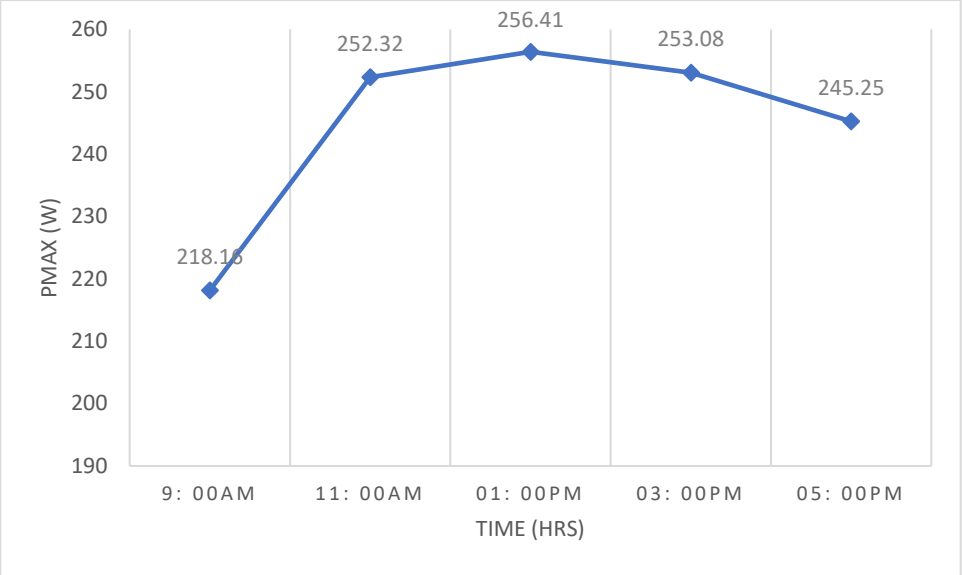

Figure 1: A graph of P_{max}against time for a clean panel

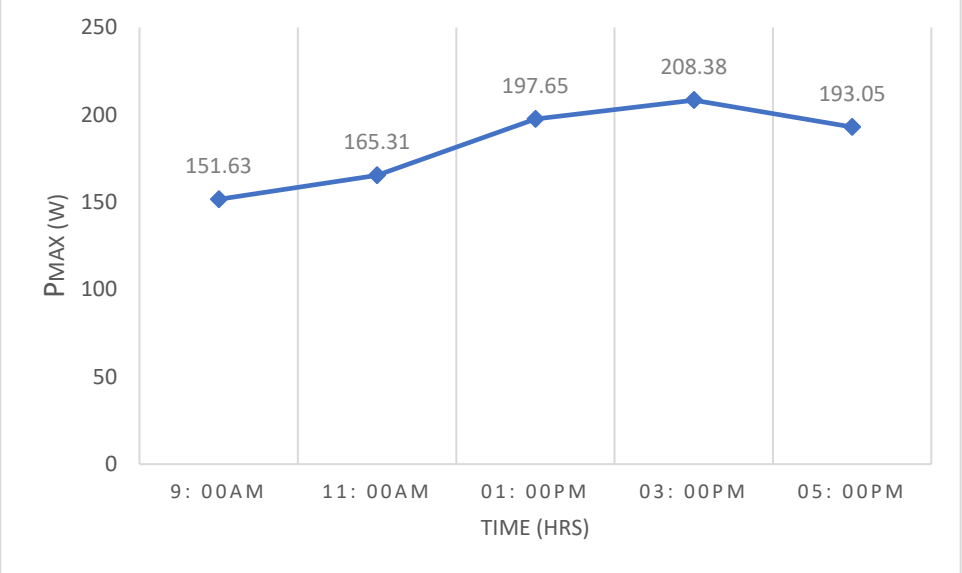

Figure 2: A graph of P_{max} against time for panel with artificial dust

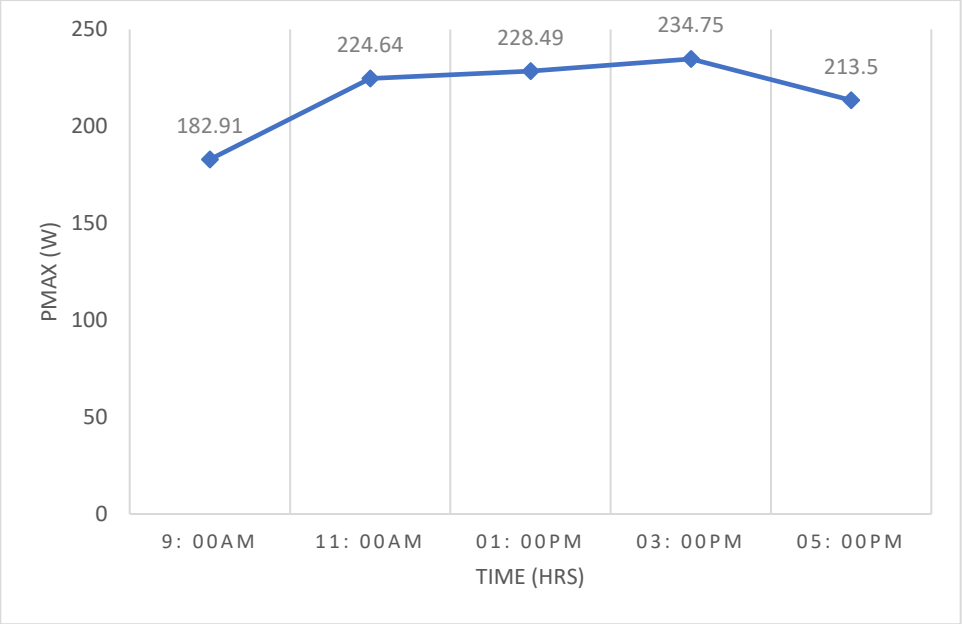

Figure 3: A graph of P_{max} against time for a panel with natural dust

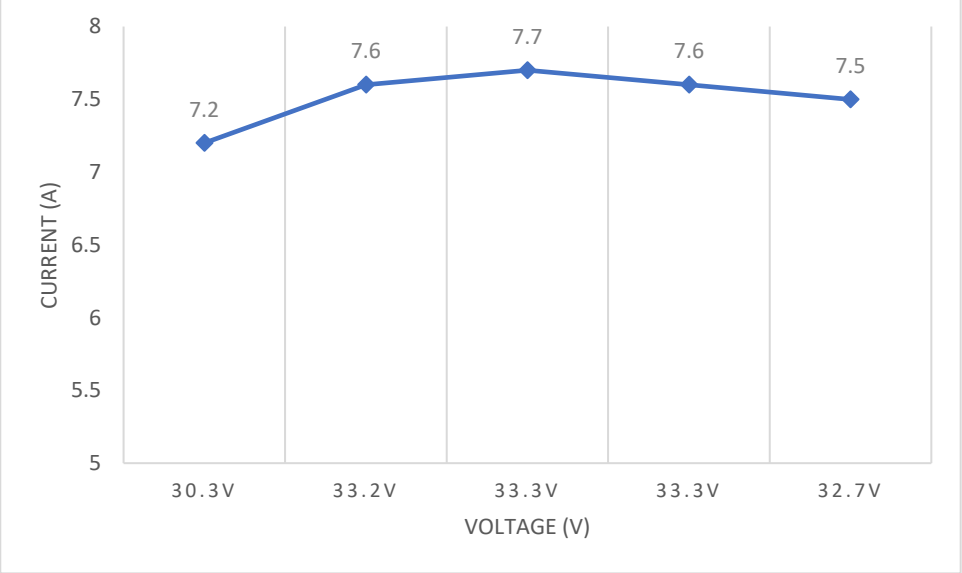

Figure 4: A graph of current against voltage for a clean solar panel

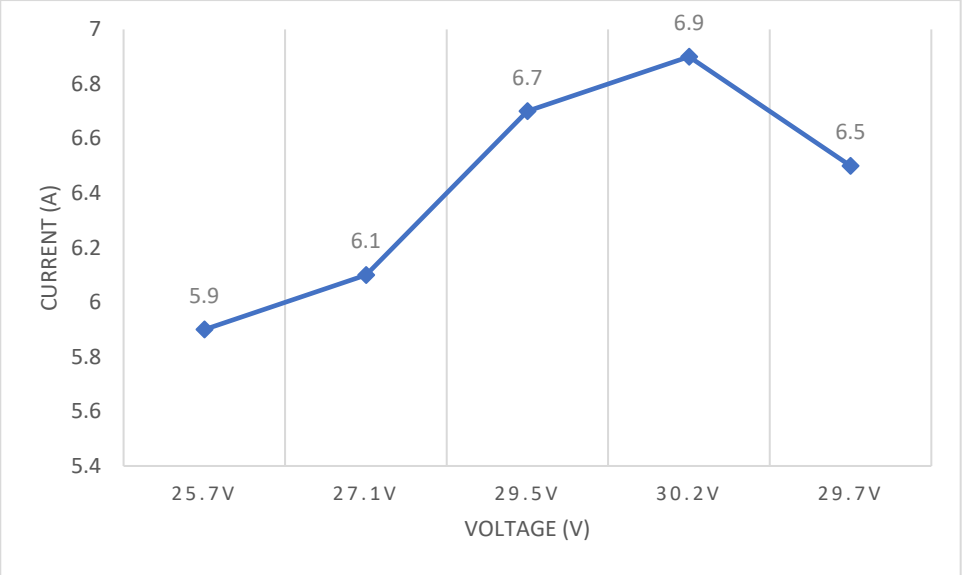

Figure 5: A graph of current against voltage for a panel with artificial dust

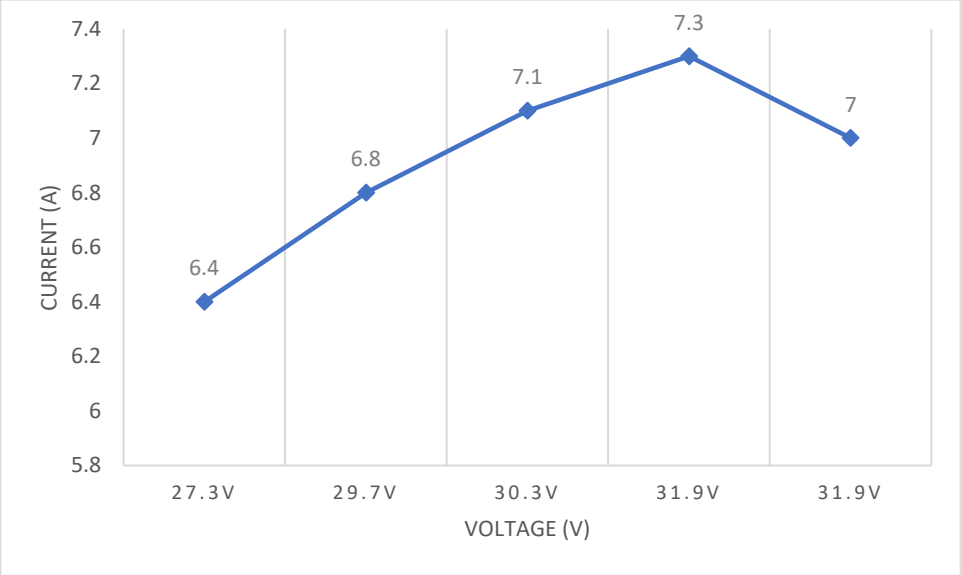

Figure 6: A graph of current against voltage for a panel with natural dust

From the graphs above, Fig. 1, 2 and 3 Shows the experimental P_{max} against time characteristic for a clean panel and also shows the experimental P_{max} against time characteristics for a panel with natural and artificial dust. The graph indicates the best performance time of the solar PV panel to be around 1:00pm for the clean panel and for the panel with dust its peak values is at 3:00pm, the panel with dust on it did get affected by the dust accumulated leading to the decrease in output power. From the graph it indicates that power output started rising from around 9:00am to its peak at 1pm and start dropping from around 3pm. Therefore, the maximum power output of solar PV panel banks on the time frame of the day. This agrees with (Kazem et al., 2019). Fig. 4: The graph shows current against voltage for a clean solar panel from the experiment conducted, it shows that the clean panel is at its peak current is 7.7A at 33.3V, at voltage 30.3V the current was 7.2A which later raised to its peak current of 7.7A. Fig. 5: The graph shows current against voltage for a panel with artificial dust from the experiment conducted, it shows that the peak value for panel with artificial dust is 6.9A at 30.2V. Fig. 6: A graph showing current against voltage for a panel with natural dust, it shows that for panel with artificial dust there is a difference from the clean panel, the peak value for panel with artificial dust is 7.3 at 31.9V.

The impact of accumulated dust on the efficiency and performance output of the solar photovoltaic panels has been widely studied, with results consistently indicating significant performance degrading. Hottel and Woertz (1942), found that dust accumulation on solar panels significantly reduces their efficiencies by blocking sunlight and increasing thermal losses. Sulaiman et al. (2011), found that accumulated dust significantly reduces photovoltaic panel efficiency by blocking sunlight and decreasing their overall power output. Specifically, they found that even a small amount of dust can lead to a noticeable drop in efficiency. This study shows a drop in efficiency, this research shows the correlation between dust accumulation and reduced maximum power output due to the drop in both voltage and current values for the panel with dust.

CONCLUSION

This study demonstrates that accumulated dust significantly impairs the efficiency and performance of solar photovoltaic panels. Research consistently demonstrates that even minimal dust coverage leads to substantial energy production losses, it underscores that even minor dust coverage can diminish energy output over time. The mean efficiency for the clean panel is 14.98%, the mean efficiency for panel with artificial dust is 11.19% and that of the panel with natural dust is 13.25%. The mean power P_{max} for the clean panel is 245.04 W, P_{max} for panel with artificial dust is 183.20 W and P_{max} for panel with natural dust is 216.86 W. This study shows the correlation between dust accumulation and reduced maximum power output due to the drop in both voltage and current values for the panel with dust.

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