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Real-time investigation of dust collection effects on solar PV panel efficiency

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Abstract

The amount of the light distraction on the PV is made by the accumulation of particles of dust which in turn decreases efficient performance as well as leads to a reduction of money flow for the investors. More studies and tests were carried out inside the laboratories that cannot find a proper solution to mitigate the same. This study can enable the proper cleaning schedules of the PV panels as this work is being carried out on a real-time basis on the rooftops. The measurement of required parameters like irradiation, output power from the panels, and the amount of dust particles accumulated was done on an hourly, monthly, and yearly basis. It is found that nearly 8% of the performance could be dropped annually. For making a sustained operation of the PV panels it is required to have a cleaning process for 45 days intervals, especially for small-scale systems.

Keywords: Dust impact, Solar Photovoltaic, System Performance, IoT web server

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1. Introduction

Almost all power sectors in the world use non-renewable energy sources for generating their electrical energy. However as per the statistics [1], the energy source will deplete at some time in the future. So, the world should move forward with energy sources that are sustainable and eco-friendly. Of all the renewable energy sources, solar power is an environmentally friendly, abundant, and encouraging source. The benefits of photovoltaic systems are: (i) can be used in the long run (ii) can be used at any place where the availability of sun rays and (iii) can be one of the economical solutions for the electrical energy requirement.
As per the data from the International Energy Agency, there will be an increment in global energy consumption of about 53% in the year 2030 with a growth rate of 70% among developing countries. Many countries around the world follow one of the aforementioned solutions to overcome a deficit dilemma of energy through the application of green technology. It was witnessed that solar energy stands as the foremost anticipated energy source among them all the available sustainable energy resources [2], [3].
In general perception of solar PV, the cost of the system is expensive with a limited period life duration of about 25 years. It is due to pores and voids in the glass, worn-out glass, and corrosion between the cell's tracks. These parameters led to the slumping of its efficiency and could not achieve the desired output. One of the significant reasons is the buildup of dust particles atop solar cells. Moreover, bird-dropping, stains are created by stagnated water salt. However, the nature of the problem varies concerning locations. These sorts of problems make the system seem to be unappealing to the PV energy market [4]. Generally, dust settlement depends on various properties like chemical properties, size of the dust

particle, shape, and weight. Added to that, the specific size factor, environmental conditions, and weather conditions are also playing a vital role. Also, the surface of the panel, angle of tilt, wind velocity, and humidity will influence the buildup of dust particles atop the cells.

Researchers have been doing studies on dust accumulation that reveal the impact on solar cells in terms of reduction in performance. It is noted from one of the studies carried out in the United States that there was a reduction in performance by 47% [5] because of dust particles layered atop the solar surface panels. Another study discloses a reduction of 40% [6] which was carried out in Saudi Arabia. From this study, a major degradation [7] could happen when the panels are placed in the desert. Likewise, a study from Kuwait shows. the reduction in the performance from 17% to 65% which mainly depends on the tilted angle of the panels. Meanwhile, in Egypt, the report shows that the performance has degraded to 65.8% [8]. The very worst reduction of performance is recorded in Thailand where an 11% reduction is reported for a minimum of [9] one-month duration. However, all the studies carried out by researchers concentrate only on influencing the effectiveness of the photovoltaic panels but not on quantum gathering dust.

Dimensions of the dust particle play a significant role in influencing the functionality of cells. Authors [10] experimented in such a way that artificial dust particles are made to accumulate on the surface of the PV panels. Artificial dust like cement ashes, carbon particles, and limestone was put under constant halogen lamps, and they found that fine dust particles had a worse effect than coarse particles in terms of deterioration of efficiency. An indistinguishable study was carried out using different-sized dust particles (mud and talcum) [11] and found that the results supported the witness in reduction of performance. Also, it is found that the type of dust makes an impact on performance reduction. In [12], the study witnesses that there is mass reduction of performance of about 70 %. Leaving these parameters, water droplets on the surface of the PV cells are also creating a vital impact on the performances. The present work was conducted to find an impact composed of particles of dust particle buildup on the solar cell, so that this outcome may find a way to warrant optimum scheduling of the cleaning process of the PV panels. This study was carried out for nearly three months' duration with real accumulated dust particles on the panel surface. It's worth noting that there exists significant enthusiasm for deploying Solar energy production in desert or dry areas since those offer optimal circumstances conducive to flat-plane solar radiation. Due to the importance of examining the impact of dust on PV modules, numerous researchers have conducted comprehensive review studies [13]. To ensure the enduring effectiveness and environmental friendliness of solar power, it is crucial to understand the Impacts of dust on solar systems and design efficient cleaning and upkeep procedures. To ensure optimal power retention by maximizing sunlight reflection based on the angle at which the solar panel is tilted varies. It involves enhancing the extended duration performance of the photovoltaic module to improve sustainability as well as meet individual requirements [14]. It has been observed that dust has a progressive effect on various weather variables, including relative humidity, precipitation, and ambient temperature [15]. The amount of solar energy impinges on the Dust, whether settled or airborne, reduces the surface efficiency of a PV module [16]. Within the context of [17], the PV module surfaces with several dust kinds (such as carbon, cement, and limestone). When only 28 g/m2 of carbon was accumulated, the current at the electrical short was lowered down to 20% of its original level; however, a similar decrease was observed also considered for When deposits of 73 g/m² of cement, 125 g/m² of 50 1m, 168 g/m² of 60 1m, and 250 g/m² of 80 1m dust containing limestone were applied. It appeared to be made clear the Dust makeup material additionally influences Solar panel performance. According to the findings, carbon particles capture solar energy additional easily than other types of dust. The quantity of Light that reaches the solar converter and the converter's temperature rise as a result [18]. According to findings from research conducted by Rao et al, (2014) and study by Jiang et al, dust accumulation does negatively significantly influence the open circuit voltage of PV systems, but it does affect the short-circuit current, reaching as high as 30-40% in outdoor conditions environments and around 4-5% in indoor settings environments [19]. Jiang et al. (2011), noted that When dust density deposition rose above 0 to 22 g/m², there was a corresponding loss in production efficiency spanning from 0% to 26% [20]. According to [21], a persistently damp atmosphere reduces the efficiency of solar cells. More heat is being removed from the surface of the PV cell at elevated wind speeds. Additionally, increased wind speed reduces the humidity level in the surrounding ambient atmosphere, improving efficiency. However, breezes can also dislodge loose dust and keep it suspended within air, which causes the accumulation of dust on modules and causes shadowing and subpar PV cell efficiency. The losses due to soiling can be modelled in a linear manner decline [22]. The authors claim that dust deposition causes an efficiency loss of 7.4% during an average 145-day summer drought. In a 145-day drought, soiling losses would reduce a 15% efficient PV panel's efficiency to 13.9% [23].

2. Methodology of the proposed work

In this work, some vital parameters like the sun's radiation, PV power output, and the quantity of dust particles are measured. Here, the values from the solarimeter and values from power meters are stored in the data logger. The experimental setup was kept on the rooftop of the building from 1km with 60 msl. The height of the building was chosen as 40m. The location is chosen in such a way that the experimental site should be far away from the forest area and the dust generated only by human activities is taken into account.

Here, three monocrystalline solar panels with dummy glass panels are set. All the panels are properly connected with the data logger and all the dummy glass panels have the solarimeter which comprises of LDR probes and each LDR is connected to an Arduino microcontroller. For making a comparison, one of the sets of the glass panel is taken as a reference, and the other set is taken as a test set. The reference set is continuously cleaned with a time interval of 5 minutes per hour and 30 minutes per day utilizing each day, per week, and per month settings. Additionally, the test panel is cleaned at corresponding intervals aligned with the selected test mode. The schematic set is shown in Figure 1. These panels are kept in closed proximity to ensure equal amounts of irradiation and dust particle accumulation. The solarimeter is kept beneath the glass panel and power measurement is done on the panel. The measured parameters like electrical output power from the PV panels and irradiation are stored in the computer and kept in a place 5m away from the PV. Based on the [15], the dust collection is kept in the horizontal position during the month when higher irradiation would be available. From the floor at a height of 1m all the PV panels are fitted. Some tempered glass having a thickness of 6mm was used in the dummy panels.

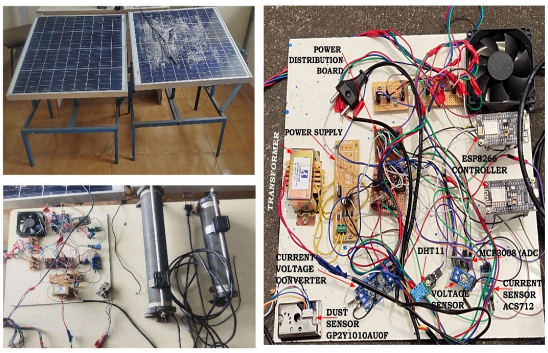

Figure 1. Experimental Setup

From the experimental setup, parameters like output power and solar intensity were found parallelly for getting the performance drop of the dummy panel. The clean panel is taken as a reference. Different tests are carried out based on Tests conducted per hour, per day, per week, each month, and quarterly basis. Nearly 8 hours should be spent taking hourly measures with the condition that all the reference panels were cleaned every hour, and the dummy panels were cleaned every 5-minute interval. All other types of tests were also done by following the same procedure with the difference in cleaning time interval. For conducting test each day, the PV panel was cleaned daily before conducting the next test. Our study primarily centers on how dust accumulation affects solar panel systems. Specialized dust detection sensors can be mounted onto the photovoltaic panels themselves towards track a buildup composed of dust. These sensors detect the level of surface dust and send real-time data to a central monitoring system. IoT systems can collect and analyze data on panel efficiency. We have installed IOT web server weather monitoring equipment on-site to track meteorological conditions in real-time. This includes sensors for temperature, humidity, wind speed, and precipitation. All sensitive electronic components and data acquisition systems are housed in weatherproof enclosures to protect them from rain, snow, and extreme temperatures.

Figure 2 shows It is an outdoor solar panel system mounted on the rooftop of a building. Sensors are connected to solar panels and data can be sensed by ESP8266 and which transmits the data to the Internet of Things web server stores data.

Sensor translates the physical quantity it perceives into a measurable electrical characteristic.

DHT11 for reading environmental temperature and humidity values.

ESP8266 has an inbuilt Wi-Fi module that reads sensor data and transmits sensor uploads information to the IoT.

IoT platform that stores all data from time to time.

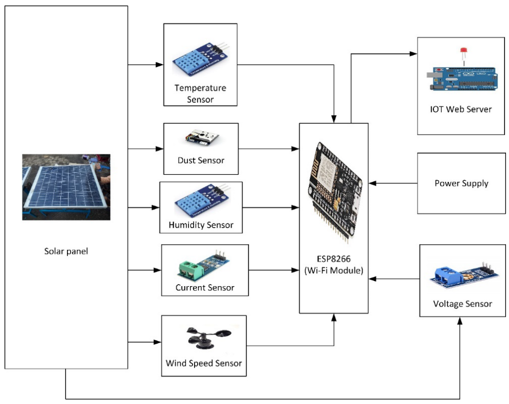

Figure 2. Block Diagram of Solar Efficiency Monitoring

Table 1. Characteristics of Elements

S.No	Elements	Class	Characteristics
1	Temperature sensor	DS18B20	Operating from 4 to 30 volts, range 0°C to 50 °C
2	Compact optical dust sensor	GP2Y1010AU0F	Range -10℃ to 65℃, operates from 2.5V to 5.5V
3	Current sensor	ACS712	Operates from 5V, Range - 5A to +5A, sensitivity 6mA/V

4	Voltage sensor	DC VOLTAGE SENSOR	Range 0 to 25V
5	Wind speed sensor		Range 4 to 20mA
6	Environment Temperature and Humidity sensor	DHT11	Operating between 3.5 to 5.5 volts, Range of 0°C to 50 °C

Table 2. The most important aspects of solar modules

Specifications	Poly-Crystaline
Maximum rated power (Pmax)	80W
Voltage at rated operation (Vmax)	19.50 V
Current at rated operation (Imax)	4.35 A
Voltage under open-circuit conditions	23.45 V
Current in a short-circuit scenario	4.65A

Figure 3. Solar Panels

3. Results and discussion

The experimental tests were conducted based on time and the results were presented in the same way as an hour, every day, the week, the month, and quarterly periods. The experiments were carried out only during times when no rain or haze was available since it influenced the measurements. Solar irradiation in terms of time and electrical power output is taken between 10 a.m. to 6 p.m. The discrimination is made on the graph between solar panels in clean and dusty conditions. Based on the results obtained, inferred that electrical output power measured from the dusty panel gave a reduced power output than the clean panel. Also, dust accumulation was less for a short span based on the location of the test being carried out. But the results will be different for different locations like deserts, seashores, and industrial areas.

Figure 4 shows the bar chart of accumulated dust particles, and their reduced electrical output is taken based on hours. The reduced Measurement of electrical power output and irradiation was conducted using comparing solar dust-free panel values with those covered in dust panels. Those tests are also relevant for Tests conducted over three months, on a daily, weekly, and monthly basis. Based on the test results, it is inferred that there exists a high reduction in the irradiation and output power. All the conducted tests show the same sought-after output results. The expectations outlined in the research [13, 14] proved to be precise, the more dust amassed, the greater the decrease in electric output and irradiation resulting from the covering up of dust particles over PV panels. 0.022g/0.01m2 of dust was collected with an average drop in output power of 0.05 %. Hence, the typical decrease in irradiation amounted to approximately 0.01%. (I). Power Loss: It is a quantity of power measurement in Solar panels by taking different power influencing with and without dust particle deposition. (II) Calculation of Efficiency: It is a ratio of power and Irradiance per sq.m. That implies,

% of Efficiency (η)= {(V x I)/ (Irradiance x area)}x 100 (1)

For pure panel:

(%η) pure= {(Vpure x Ipure)/ (Irradiance x area)}x 100 (2)

Where, area=0.7051m2

For dust panel:

(%η) dust= {(Vdust x Idust)/ (Irradiance x area)}x 100 (3)

For efficiency reduction:

(%η) reduction= {(ηpure - ηdust)/(ηpure}x 100 (4)

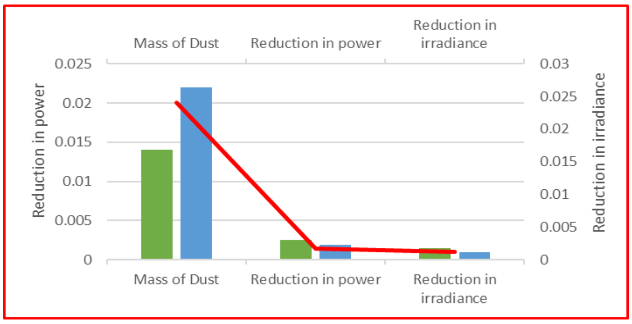

Figure 4. Hourly Test Sample Results

From Figure 5, it was inferred that the final collection of dust particles and final electrical power reduction and irradiation were measured daily. It was found that 0.025/0.01m2 of dust was conducted on an hourly basis which in turn reduced 0.5% power output and 0.4% of irradiation. The same trend of results is also shown in Figure 7, which depicts the differences are less. It is understood from the result that the irradiation and electrical output are directly proportional to dust accumulation.

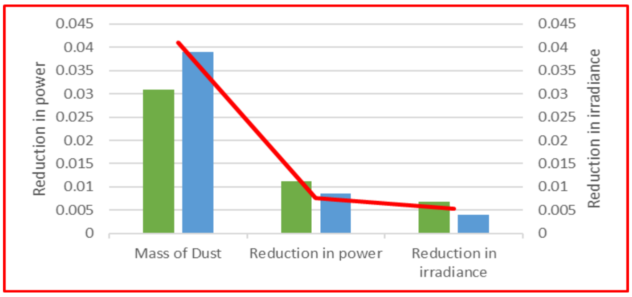

Figure 5. Daily Test Sample Results

From the weekly test results shown in Figure 6, they reveal the reduction of electrical power and irradiation weekly. The total dust collected was about 0.03g/0.01m2. With this accumulation of dust, the final output power reduction goes to 1.1 % and that of irradiation to about 0.9 %. As noted from the previous test, the reduction of power output and irradiation is correlated directly using a quantity dust particle present in solar panels.

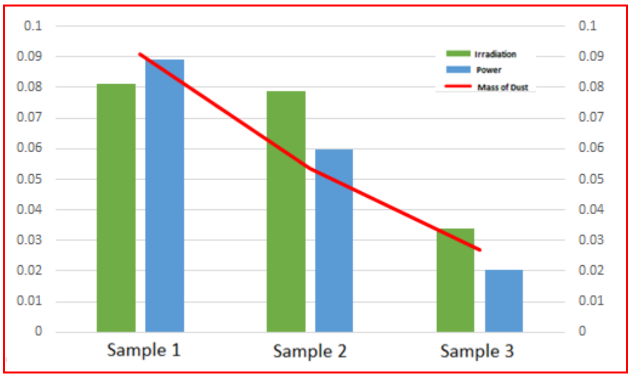

Figure 6. Test Conducted Every Week Sample Results

Monthly results are shown in Figure 7, where the amount of dust collected was 0.038 g/0.01 m2 and the mean decrease of irradiation and power generation was 1.2 % and 1.5 % respectively.

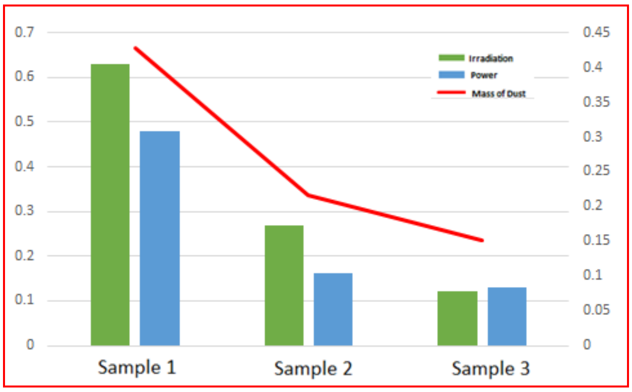

Figure 7. Monthly Test Sample Results

The 8 figure provides the mean dust mass accumulation carried out in all tests using 0.01 m2. It is found that the buildup of dust on the solar panels happens quicker on an initial day and increases slowly over a few months. Results give a steady graph even Results of tests which suggested that newly cleaned glass surface could trap dust particles more effectively than the soiled panel. No explanation can be offered contributing to the quicker buildup of dust on the pristine glass panel. The results shown in the histogram of Figure 8 disclose the reduction of electric power generation affected by the buildup of dust done by distinct panels. It also indicates electrical output decreases gradually from hourly testing to monthly testing.

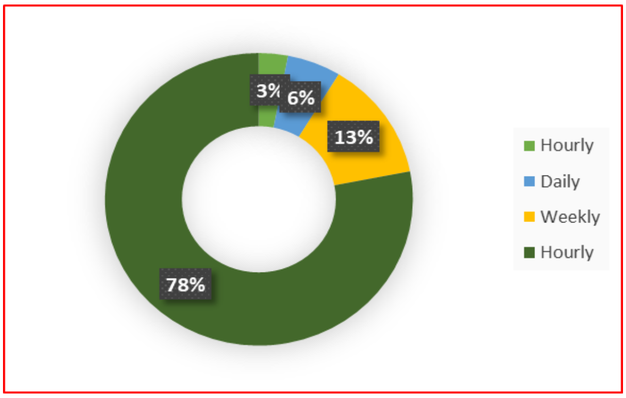

Figure 8. Overall Collection of Dust Particles

4. Conclusion

The goal of this study was to learn more about how dust deposition affects PV module performance in arid environments. Several performance metrics of two panels (clean and unclean) were recorded. While both panels were subjected to the same conditions, only one was regularly cleaned during the course of the study. The panel's performance was examined by producing various characteristic curves. This research will allow for more efficient cleaning regimens for PV panels to be implemented in real time on rooftops. Hourly, and monthly measurements of critical parameters such as irradiation, panel output power, and dust accumulation were taken. The research shows that a yearly performance loss of around 8% is possible. Conversely, a cleaning process at 45-day intervals is essential to ensure the long-term functionality of the PV panels, especially for smaller-scale systems.

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