Analysis of dust on the parameters of PV module and design of an effective solar dust cleaner

Arjyadhara Pradhan, Babita Panda, Lipika Nanda, Chitralekha Jena
School of Electrical Engineering, Kalinga Institute of Industrial Technology, Deemed to be University, Bhubaneshwar, India

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ABSTRACT

Photovoltaic panel output is affected by various factors like solar isolation, temperature, dust, shading, mounting. Among all these factors dust is a prominent factor which greatly reduces panel efficiency. With increase in the quantity of dust both efficiency and power output of the module reduces. As the mass of dust deposition increases, power output and the efficiency of the module decreases. Dust particles are of different shapes and sizes. PV panels installed on ground or roof top are subjected to dust all the time. The amount and type of dust deposition depends on tilt angle, locations, surroundings nearby, rainfall pattern of that area, maintenance method of the installer. PV plant nearby any industry giving out lot of fumes and smokes will have heavy dust deposition over its top surface. Similarly, PV plants located near areas where roads are not concrete can cause dust deposition on its panels. Manual maintenance is labor costing and less efficient. In this work we have performed dust analysis on the performance of PV panel and designed an effective method to clean the panel and make it dust free. Solar dust cleaner and cooler system provides a solution for both dusts cleaning and keeping the panels at less temperature.

Corresponding Author:

Arjyadhara Pradhan
School of Electrical Engineering, Kalinga Institute of Industrial Technology, Deemed to be University
Patia, Bhubaneshwar, Odisha 751024, India
Email: arjyadhara.pradhanfel@kiit.ac.in

1. INTRODUCTION

Human needs are ever increasing. Rapid industrialization and techno development worldwide has put stress on the use of conventional sources like fossil fuels. These sources are limited and create a lot of pollution. Using non-conventional source like solar energy is clean, eco-friendly and economic also. Photovoltaic panels become a promising solution reducing the burden of usage of conventional source which in turn prevent carbon dioxide concentration in the atmosphere hence we can say global warming can also be reduced. PV systems are mostly outdoor system which is always prone to external environmental conditions. These affect the panel performance in terms of efficiency, power output and fill factor. Several researchers have stated that the total amount of solar radiation falling on the panel are not completely utilized as electrical energy but only some portion is converted and the remaining is transferred as heat energy increasing the temperature of the module. Thus, temperature has a negative relation with efficiency and maximum power. Open circuit voltage decreases by 2.2 mV for every one degree increase in temperature. Electrical performance of photovoltaic panels is greatly reduced by the deposition of dust particles on the surface of photovoltaic panels. Hence removal of the dust is very required for improving the performance. An automatic sprayer designed for cleaning the PV panel uses closed water cycle and consumes less energy [1]. In desert areas dust creates shadows over the PV panels and reduces their efficiency. Output power decreases on prolonged exposure of panels to dusty atmosphere. Regularly two weeks interval cleaning is recommended by Abdelsalam *et al.* in his work [2]. Jamil *et al.* in his paper stated that the severity of effect of soiling is dependent on location and environment. A poly-crystalling PV module was considered for study and was found that soiling reduces the module's output by 20% [3]. Soiling causes loss of power and it is based on physical and chemical properties of the dust particles as well as geographical locations is one of the other factor on which it depends [4]. e concluded that all wind speed cannot be for dust cleaning rather velocity of wind from 1m/ to 22m/s can be effectively used [5]. Dust deposition can be greatly reduced if scheduled cleaning is done as suggested by Yadav *et al.* [6]. Margaret *et al.* [7] highlighted in his studies about robot cleaning method by using micro-controller and then again it will increase the overall system cost. Wind cleaning process is one of the dust cleaning method as described by Jiang *et al*. [8]. He also suggested that wet cleaning method is better then dry cleaning. But wet cleaning method will cause unnecessary water use. Some researchers also concluded that automated cleaning generates 35% more power output then manual cleaning by using ionic surfactants. Anionic surfactant respond more better to the dust deposited on the PV panel [9].

Many researchers compared the different MPPT methods and stated the effect on the performance of PV panel [10]. He used Matlab/Simulink to carry out the analysis. He concluded that fuzzy logic method is robust method in comparison to perturb and observance and incremental conductance method [11]. Photovoltaic systems are used in various fields like island micro-grid [12]. In every platform these panels are exposed to outer conditions where dust is a most common phenomenon [13].

2. RESEARCH METHOD

Dust analysis is carried out by conducting a real time experiment. We have considered two photovoltaic modules each of 37 watt one with clean condition and other with dusty condition. In this experiment and the hardware shown below figure the voltage and current of the PV module are received by the sensors and these sensors give signal to the MPPT controlled micro-controller. The sensors also give input to the step up converter [14]. In this case the boost converter is connected with a resistive load. A LCD display unit is used to show the value of power output of the converter [15].

The Figure 1 shows the use of voltage sensors, current sensors, a boost converter, micro-controller, LCD, and a supply system to supply power to the controller. Here a 12 V battery is used. In this experimental study, three main important parameters are calculated for each external factors like maximum power, module efficiency and fill factor [16]. Fill factor is the indicator of the quality of the cell [17]. It is the measure of squareness of a solar cell [18]. Generally, it lies within 0 to 1 range [19].

$$Pmax = Vmax \times Imax \tag{1}$$

Where P_{max} is the maximum power obtained from the PV module, V_{max} is the maximum voltage, I_{max} is the maximum current. V_{oc}: open circuit voltage, I_{sc}: Short circuit current.

$$\text{Efficiency (\%)} = \frac{Pmax}{\text{Solar irradiance} \times \text{area}} \tag{2}$$

$$\text{Fill factor} = \frac{Pmax}{Voc \times Isc} \tag{3}$$

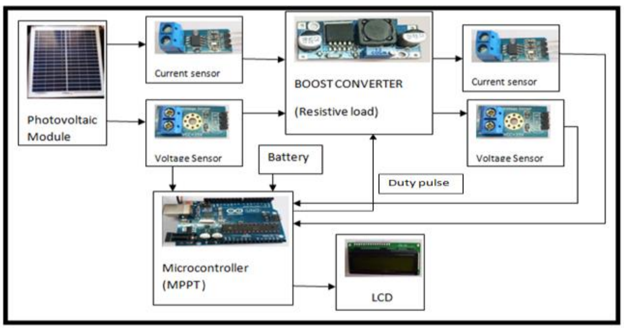

Figure 1. Interconnection of different elements with PV

The various components or devices used for this experimental procedure include: photovoltaic module, resistor, inductor, capacitor, voltage sensor, current sensor, and boost converter, controller (ARDUINO), mosfet, diode, led, LCD, and battery. The 37 watt PV module of make vikram solar is used for the experiment. The voltage sensor used is of 5 volt [20]. Hence module input voltage is taken as 25 volt. The current sensor used for arduino is ACS712. The converter unit has two input capacitors each 100 micro-farad, 25 volt. N channel mosfet IRF 540N and 3 inductors of 10 micro Henry in series. Diode IN4007 is used. Output capacitor of 470 micro-farad is used. 1kohm resistive load is considered for the experiment. ATmega328 is the micro-controller used. Battery set of three units are considered each with 4 volt and 1 ampere, 1 AH.

In this work road side, dust was considered for the experiment. Different quantities of dust were measured and by the help of sieve dust [21] was spread on the PV module. The experiment is conducted at a fixed irradiance i.e. 800 W/m^2. Dust prevents the total amount of radiation falling on the panel to get effectively converted to useful energy [22]. Two set up are considered and the experiment was conducted for an entire day during the sunshine hours. Figure 2 shows the experimental setup with dust spread on the PV module. Figure 3 shows the clean PV module for the test.

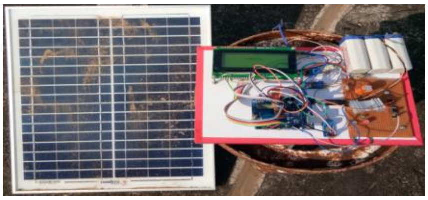

Figure 2. Set up considering soiling condition

Figure 3. Setup at clean condition

3. PROPOSED METHOD

In order to clean the panel and make it dust free we have designed a solar dust cleaner This new cleaning system can be extended to the real time solar power plants. Solar dust cleaner and cooler is a very effective system to reduce panel losses and hence increase efficiency [23]. Thus PV industry can be befitted a lot. Maximum efficiency can be achieved by designing efficient cleaning and cooling system [24], [25]. In this work we have designed a automatic system to sense presence of dust and increase in temperature, then clean and cool the panel with the help of vibrators and cooling arrangement respectively. In order to achieve this many innovative features are used.

As shown in Figure 4 solar dust cleaner and cooler consists of transparent plastic sheet laced on the upper layer of the PV panel. The dust gets deposited on the sheet. The thin flexible planar shield acts as barrier. Spacing membranes are placed at the corners along the edges of the photovoltaic panels for supporting the shield. The planar sheet is properly designed with the dimension of the PV panel to fit on the top so that when it is disposed it covers all the PV elements and protects it from dust and dirt. Four membrane vibrators are placed on the four corners of the panels. The work of these vibrators is to shake the sheet so that dust particles can be dislodged from their positions. They operate at resonant frequency of the shield so that a standing wave can be created to loosen the dust particles more efficiently. For cooling purpose air compressor is used which compresses the air to be passed through the nozzles. The compressor is supplied by photovoltaic panel. Air compressor is operated for short duration. There are several distribution nozzles where the compressed air is passed instead of using water for cooling purpose. When the compressed air passes through the nozzle the dust particles settled on the panels are removed as well as the panel gets cooled. This overall increases the performance.

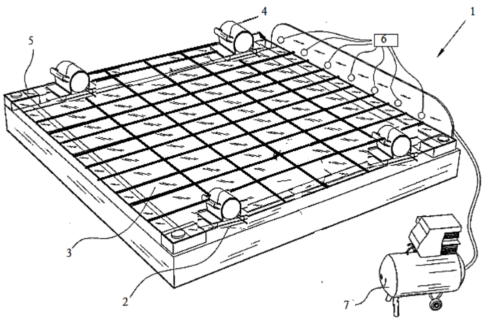

Figure 4. Perspective view of the solar panel cleaner

Figure 5 shows the electrical circuit. It consists of micro-controller mostly Arduino Uno is used to control the entire process. A sensor is used in the micro-controller to sense the amount of dust and on reaching a set level vibrators are operated. The power inverter has two input one from PV panel and one from battery. The outputs of the inverter are connected to a boost device namely step-up device and also to AC load**.** The output of step up device is connected to a switch to power the air compressor and vibrators, which can be switched ON and OFF as per the requirement. Also, the micro-controller is connected to switch to control all the operations related to ON/OFF of air compressor and vibrators**.**

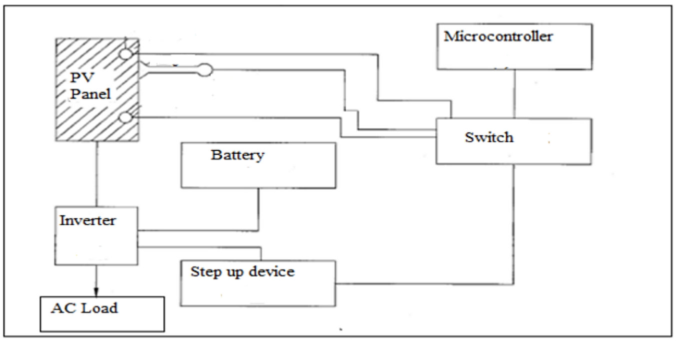

Figure 5. Block diagram representation of internal electric circuit

4. RESULTS AND DISCUSSIONS

In the experiment conducted open circuit voltage and short circuit current values are calculated for different quantities of dust. Different samples of dust are considered and uniformly spread on the modules under test. The results are compared with that of clean module.

From Table 1 it was found that with increase in dust deposition short-circuit current changes remarkable whereas open circuit voltage changes very slightly. Effect of different quantities of dust was analyzed to verify how the PV panel maximum power, fill factor and efficiency are affected. It was clearly observed that all the mentioned factors decreases with the presence of dust and also with quantity of dust. Table 2 shows the effect of various parameters like cell temperature, short circuit current, open circuit voltage and average power at different values of solar irradiance on the panel both for clean and dusty condition.

Figure 6 clearly explains that with increase in the quantity of dust both efficiency and peak power reduces. From the Figure 7, we can conclude even fill factor are also affected by soiling condition of PV panels. Figure 8 shows that the cell temperature is more for dusty panel in comparison to clean panel at different solar irradiance. Figures 9, 10, 11 shows that short circuit current, open circuit voltage and average power decreases at dusty condition in comparison to clean panel for different values of solar insolation. Clean panel performs much better and also increases efficiency of the system. Cleaning either by manual or automatic is recommended but again manual cleaning is not perfect and also labor intensive hence in order to save time and labour automatic solar cleaner is preferable.

From Table 3 it is clear that dusty panels modules give less output voltage and current in comparison to clear modules. V1: input voltage, V2: output voltage, I1: Input current, I2: Output current, P1: Input power, P2: Output power. From Table 4 it is clearly seen that in dusty panels the decrease in short circuit current, maximum current and efficiency increases with increase in time of exposure of the panels. An analysis on daily, weekly and monthly basis is drawn to find the result. From Table 5 it is clear that using solar dust cleaner all the parameters considered in this study are improved on both daily, weekly and monthly basis of exposure of panels to atmospheric condition.

Table 1. Values of V_{oc} and IsI_{sc} for different quantities of dust

Sl no	Dust(gm)	Voc (Volt)	Isc (Ampere)
1	5	19.6	1.73
2	3	19.9	1.86
3	2	20.3	1.97
4	1	20.5	2.08
5	0.5	20.8	2.21
6	No dust	21.0	2.43

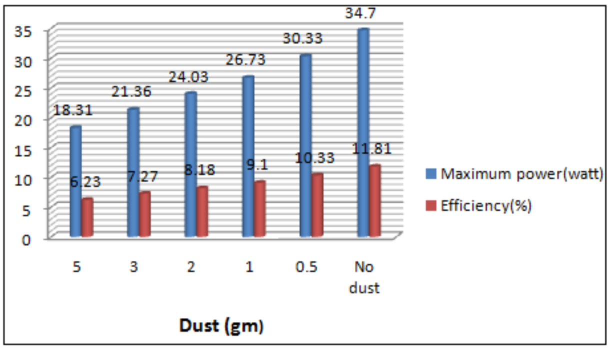

Figure 6. Maximum power, efficiency using various quantity of dust on the module

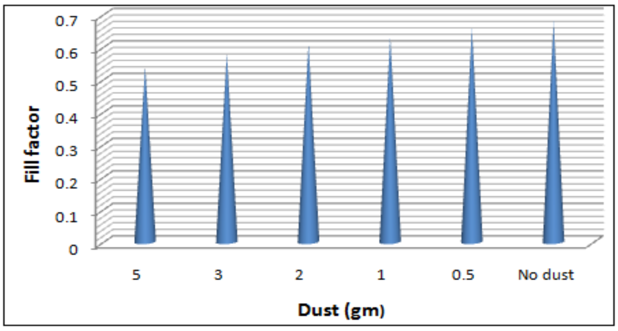

Figure 7. Value of fill factor for a different quantity of dust

Table 2. Values of different parameters with variation in intensity

Sl No	Intensity (watt/m^2)	Cell Temperature (Deg Celcius) Clean	Dusty	Short circuit current (Ampere) Clean	Dusty	Open circuit voltage (Voltage) Clean	Dusty	Average Power (Watt) Clean	Dusty
1	240	42.8	44	0.084	0.052	17.4	17.3	0.98	0.64
2	480	36.4	38	0.213	0.146	18.3	17.7	2.86	1.69
3	660	30.2	32	0.249	0.168	18.8	18.6	3.34	1.96
4	784	26.9	28	0.312	0.181	19.2	18.94	3.84	2.34
5	890	23.1	24	0.439	0.191	19.8	19.6	3.98	2.46

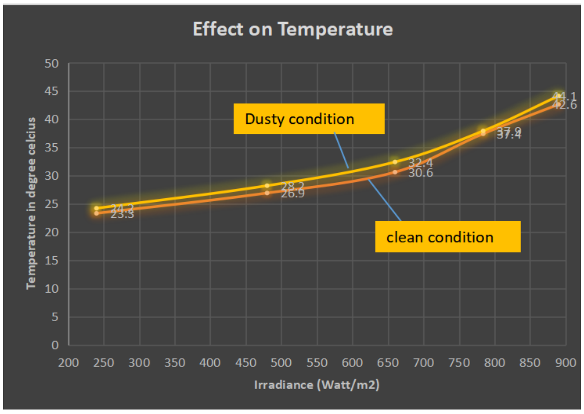

Figure 8. Effect of soiling and clean condition on cell temperature

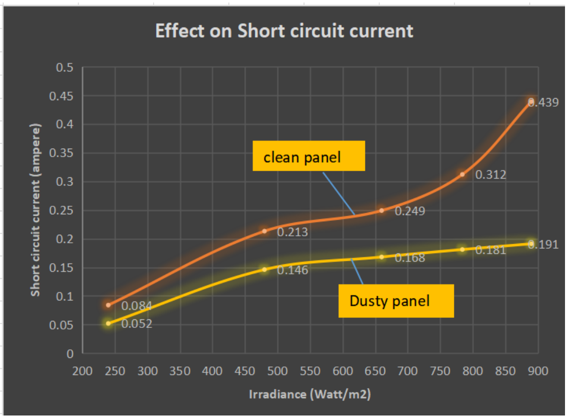

Figure 9. Effect of soiling and clean condition on short circuit current

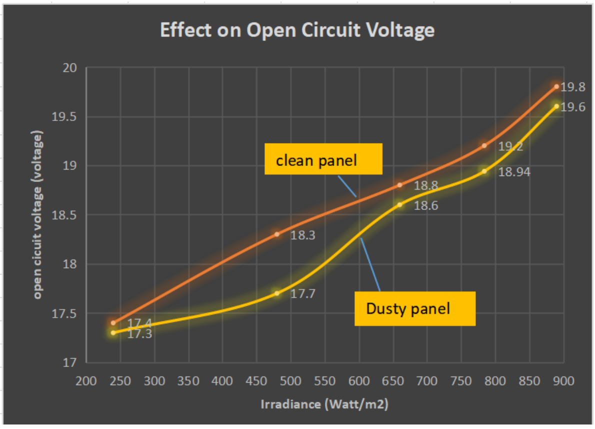

Figure 10. Effect of soiling and clean condition on open circuit voltage

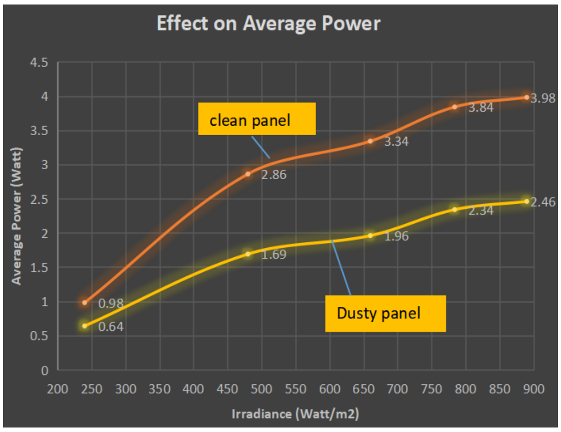

Figure 11. Effect of soiling and clean condition on average power

Table 3. Shows the input-output readings of the converter for dust condition

Sl no	Dust condition	V1 Volt	I1 mA	P1 Watt	V2 (Volt)	I2 mA	P2 Watt
1	Dusty	18.92	75.47	1.428	19.08	67.13	1.281
2	Clean	19.34	83.60	1.617	19.27	82.20	1.584

Table 4. Percentage decrease of short-circuit current, maximum current and efficiency on daily, weekly and monthly basis

Time of measurement	Decrease in Isc (%)	Decrease in Im (%)	Efficiency (%)
Daily	6.9	5.87	4.81
Weekly	12.8	10.57	9.23
Monthly	16.4	18.32	14.16

Table 5. Percentage change in efficiency, short-circuit current, open circuit voltage and average power on timely exposure of solar panel to dust and using solar dust cleaner

		Change in Efficiency (%)		Change in Short circuit current (%)		Change in Open circuit voltage (%)		Change in Average Power (%)	
Sl No	Time of Measurement	Using solar dust cleaner (SDC)	Dusty	Using (SDC)	Dusty	Using SDC	Dusty	Using SDC	Dusty
1	Daily	12.3	6.4	7.2	6.9	8.3	6.2	8.5	7.1
2	Weekly	18.4	19.3	14.4	12.8	15.4	14.2	16.2	13.8
3	Monthly	26.1	32.2	18..6	16.4	19.3	16.3	20.1	18.2

5. CONCLUSION

In this paper experimental analysis is carried our to find the effect of soiling on various parameters of PV panels. The results show that short circuit current, open circuit voltage, maximum current, average power, cell temperature and efficiency decreases with increase in the exposure time of dust over the panel. The system performs better under clean condition. Hence a solar dust cleaner is designed and tested to see the effect on the panel. In this design four number of Membrane vibrators are used. The specialty of using four vibrators is that the dust deposited on the PV panel will be uniformly cleaned from the entire panel thereby increasing the efficiency of the system. Like other design process if only two vibrators are present then on actuating the vibrators dust will be dislodged from the top surface but depending on the size of the PV panel and dust particles, some particles will get accumulated at the bottom layer. This creates unevenness at the PV panel surface which may result in formation of hot spot. A feedback system is used in the micro-controller such that when the dust level increases and reaches the set point the vibrators are operated to clean the panel. An analysis was also carried on daily weekly and monthly basis to see the effect of dust on the panel with the use of dust cleaner and that without. Even PV panel inclination also greatly matters for dust deposition and removal process.

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BIOGRAPHIES OF AUTHORS

Arjyadhara Pradhan is working as Assistant Professor in the school of Electrical Engineering since 2011. Dr. Pradhan holds a B.Tech Degree in Electrical Engineering from KIIT University in the year 2009, M.Tech Degree in Electrical Engineering from KIIT University in the year 2013 and Ph.D from KIIT Deemed to be university in the year 2018. Dr. Pradhan research area is green energy with focus on solar photovoltaics. She has 16 scopus index publications and eight patent. She received "Young Engineer" Award in the field of electrical engineering in the year 2020. She has ten years of academic experience. She can be contacted at email: arjyadhara.pradhanfel@kiit.ac.in

Babita Panda received the Master Degree in Power Electronics and Drives in 2009 & Ph.D. degree in Electrical Engineering in 2017 from KIIT, Deemed to be University, Bhubaneswar, India. She is working as an Associate Professor in the department of Electrical Engineering at KIIT since 16th August 2012. Her research areas include power electronics and drives, distributed generation, renewable energy, standalone and grid connected photovoltaic system. She can be contacted at email: babitapfel@kiit.ac.in.

Lipika Nanda is Assistant Professor (ll), School of Electrical Engineering, KIIT Deemed to be University has more than 15 years of teaching experience. She has published many SCI and SCOPUS Indexed research articles in international and national journals and conferences. She was conferred with the "Innovative researcher and Dedicated Best Academician Award 2020" in 2020. She can be contacted at email: lnandafel@kiit.ac.in,orchid.

Chitralekha Jena awarded Ph.D in the year 2017 from Jadavpur University, Kolkata. She is working as Assistant Professor in School of Electrical Engineering since 2012.Her research are optimization of different power system using meta heuristics techniques, power management of smart grid,load frequency control,improvement of power quality using energy storage device.She has got best paper award from Institution of Engineers in the year 2017. She can be contacted at email: chitralekha.jenafel@kiit.ac.in.