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Effect of Dust Physical on the Performance of Poly-crystalline PV Module based on Indoor Experiment

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ABSTRACT

Dust accumulation on PV module surface or known as soiling phenomenon is one of the environmental factors that contribute to PV module performance reduction. Its presence will reduce the absorbance of sunlight and the energy being converted into electricity. This issue has been discussed in various studies to highlight its impact on PV system performance and reliability when exposed under actual operating conditions. In addition, the surrounding environment, climate behaviour and rise in module temperature are other factors affect the PV energy output and these factors are unpredictable and difficult to justify. This paper presents an experimental-based approach to investigate the effect of soiling on PV module performance in a laboratory condition. The indoor experiment involved with accelerated artificial dust loading for testing dust physical property which is the density of dust accumulation, relative size and dust colour. The findings show that proliferation of soiling density has severe effect to the short circuit current (I_{sc}) but minimal to open circuit voltage (V_{oc}) reduction. On the dust particle relative size, the result has proven that the finer dust particle in soiling can reduce the PV module performance more than the coarser particle. Meanwhile, the brighter dust tones and colours are found to reduce module performance more than the darker one.

Key Words: Dust physical; Soiling; PV module; Performance; in-door experiment.

1. INTRODUCTION

Generally, worldwide electricity generation is mainly produced by using non-renewable energy sources, especially fossil fuels. However, these resources is depleting at some time in the close future [1]. Such a situation forces us to look for alternative energy resources which are environment friendly, no pollutant and available freely. Solar Photovoltaic (PV) due to its advantages in both technological and economic aspects is the most preferred where the technologies have been expending throughout the world. According to International Energy Agency (IEA) through their report in World Energy Outlook (WEO) 2014 Edition, PV is ranked as third largest share of RE based power generation which is at 18%, behind wind power (34%) and hydropower (30%). Also mentioned in the 'Renewables 2015 Global Status Report', the total global capacity of PV power systems has escalated from 3.7 GW in 2004 to about 177 GW in 2014, and 40 GW was contributed in the end of 2014, indicated more than 60% growth.

The output of a PV module is usually rated by manufacturers under Standard Test Conditions (STC), where each module is tested under a temperature of 25 ^{o}C; solar radiation of 1000 W/m^2, air mass of 1.5 and wind speed of 2 m/s. Typically, the solar conversion efficiency of PV modules ranges from 10 to 13% in commercial level. However, the efficiency of outdoor installed PV modules may be further reduced by 10 to 25% due to the losses in the inverter, wiring and dust pollution [2].

In the atmospheric condition, shading from cloud, module heating (from ambient temperature and sunlight radiation), less solar irradiance due to the bad weather (rain, snow), vegetation of lichen or moss[3] [4] and soiling on the module surface are the factors which contributes to the reduction of power output from the PV module. Figure 1 shows the illustration of dust deposition on the PV module surface. In addition, with high humidity existence the dust accumulation on PV surface willl gives a hard layer cleaning resistance. Darwish et al. [5] clarifies that there are limited current research characterizing deposition of dust and their impact on PV system performance. As a result, the dust deposition is a complex phenomenon that must be dealt with its diverse site-specific environmental and weather conditions sources. According to Mani and Pillai, dust is a term normally applied to minute solid particles with diameters less than 500µm [6]. The presence of soiling will block part of the direct solar irradiation and reduce the absorbance ability by PV module.

Figure 1: Accumulated Dust or Soiling on PV Module's Surface

Jiang et al conducted an experiment in the laboratory found that there is a linear relationship of PV module efficiency reduction with the increment of dust density from 0 to 22 g/m² where it decreases from 26% to 0% [7]. Also, Sulaiman et al who studied the different type of dust effect on a PV module performance in the laboratory experiment discovered that 60% to 74% of power output reduction due to dust accumulation [8]. Similar experiment [6] was performed by Kazem et al and they found that 4% to 24% of open circuit voltage, V_{oc} reduction when different types of dust are tested; ash (24%), sand(4%), silica, calcium carbonate, and red earth [9].

In addition to the above mentioned subject, an outdoor experiment are also studied by several researchers to conform there is a decrease of PV performance when been exposed to atmospheric conditions. Kalogirou et al conducted the outdoor experiment in Cyprus monitored and found that the system performance reduction up to 43% caused by airborne dust. [10]. Zorrilla-Casanova et al from Spain indicated from their daily observation, the PV system mean annual energy loss due to soiling is 4.4% and it can even go higher to 20% if in long dry season without rain [11]. Also, Adinoyi and Said in their work, they experienced more than 50% power output reduction from the impact of soiling for the system exposed outdoor [12]. Klugmann-Radziemska discovered 0.8 % maximum daily efficiency loss of installed PV system with an average maximum power decrease of 3% per year [13]. Pavan et al observation on the large scale installed PV plant in Italy revealed that power losses from 1.1% to 6.9% due to soiling. Although the percentages of power losses seem small but the implication to the financial benefit obtains from the plants is greater [14].

The effect of dust on PV modules performance has been investigated in different ways as can be found in the literature. However, less study was conducted to observe the soiling effect when different dust physical features deposit on the PV module surface. Therefore, this indoor experiment is performed to investigate and compare the effect of dust physical such as density, particle size and colour tone of the different types of artificial dust to the PV power output.

2. EXPERIMENT METHODOLOGY

In this study, a poly-crystalline photovoltaic module is used. This module rated at 80 W_p (Watt peak (maximum power), 17.2 V_{mp} (Volt (voltage maximum point)), 4.65 A, A_{mp} (Ampere (current maximum point)) at Standard Test Condition (STC) and weight over 8 kg with dimension 37.01 inch (length) × 26.57 inch (width) × 1.18 inch (thickness). The indoor experiment set-up is as shown in Figure 2. The PV module is connected to a monitoring system (HT Italia I-V400) which able to logged in module's voltage, current, power, resistance and temperature. An artificial lighting of two halogen lamps at 500 W each is used as solar source to produce variations of intensity with respect to distance.

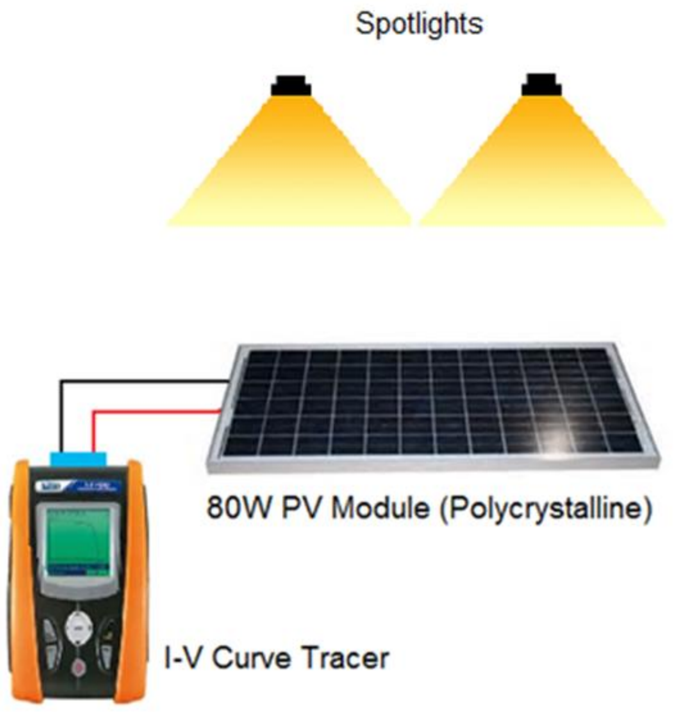

Figure 2: Dust Physical Experiment Set Up

The experiment was performed in the confined laboratory room, isolated from the external lighting exposure and the ambient temperature being controlled at 25ºC. To irradiate the PV module, two units of spotlights was used and placed above the horizontal module with the light beam adjusted to evenly irradiate the module. At first, the irradiation value was measured at 36 different points. The irradiance values in Watt per meter square (W/m^2) at each points is shown in Figure 3. The effective area of the module is 0.5866 m^2, while the average irradiance received by the module from the spotlights is at 282.1389 W/m^2.

628 mm

130	274	238	172
153	409	385	232
156	506	489	293
173	570	534	315
219	565	479	274
267	453	367	173
261	363	240	129
136	283	202	101
153	183	183	97

934 mm

Figure 3: Measurement of Irradiation Levels at 36 Different Points by Using Irradiance Meter

In this research, indoor experiments are conducted to investigate the effect of dust physical features on PV performance. The PV module is tested using different dust elements as indicated in Figures 4 to 10. It can be observed that it comes with different color, tone and size which they are actually emulating the actual dust accumulating on the PV surface.

Figure 4: Wheat Flour

Figure 5: Fine Salt

Figure 6: Coarse Salt

Figure 7: Black Curry Powder

Figure 8: Turmeric Powder

Figure 9: Chilli Powder

Figure 10: Coffee Powder

In order to determine the impact of the different selected air pollutants on PV-panels performance, an experimental procedure is carried out in order to compare the voltage, current and power outputs of the PV module under different dust deposition conditions. Four (4) types of experiments were performed:

1. The first experiment is to observe the effect of dust weight/density:

   - Wheat flour: increases from 0 to 200 g/m² at the incremental of 10 g/m² to compare the module I-V curve of different dust density

2. The second experiment is to investigate the effect of different dust color tone:

   - Chili powder, turmeric powder and wheat flour at 50 g/m² each having the same texture but different dust color tone

3. The third experiment is to investigate the effect of different dust color tone (bright to dark) having same texture or grain size.
   - Coffee powder, cumin powder, white pepper powder and black curry powder, wheat flour at 50 g/m² each.

4. The forth experiment is to investigate the effect of different dust size particles:

   - wheat flour (small particle texture) and fine salt (less small particle texture than wheat flour) at 50 g/m² each having the same color (white).

For each experiment, the artificial dusts were loaded evenly on to the module effective surface area. Then, the spotlights were turned on for less than 10 seconds and measurements were taken by the I-V curve tracer. This step is important to ensure that no or less discrepancy to the measured data accuracy that is produced by increased of module temperature. Theoretically, the rise of module temperature has drastic effect on the output voltage and less significant to output current.

3. RESULTS AND DISCUSSIONS

For each series of experiment, the I-V curve tracer managed to construct the I-V curve respond after the artificial dust loading. Figure 11 shows the I-V curves from the first experiment using wheat flour. It is observed that, the open circuit voltage (V_{oc}) is reduced from 20.17 V to 19.18 V, the short circuit current (I_{sc}) is reduced from 0.84 A to 0.47 A and the output power is reduced from 8.29 W to 3.50 W with the increment of dust density from 0 to 200 g/m². It indicates the reduction of 4.91 % V_{oc}, 44.05 % I_{sc} and 57.78 % maximum output power, P_{max} respectively. Hence, these imply that at the constant temperature, the presence of dust has significant effect in reducing the PV module output current and power but less significant effect to the output voltage. The results obtained proved in the theory where the PV module output current is drastically affected by the irradiation level where the dust settlement on the module surface is blocking part of the spotlight irradiation and hence reduces the irradiation level received by the module. On the other hand, less effect on the module output voltage because of the module temperature is maintained at 25ºC during the experiment and theoretically the reduction of irradiance level has marginal effect on PV module output voltage reduction.

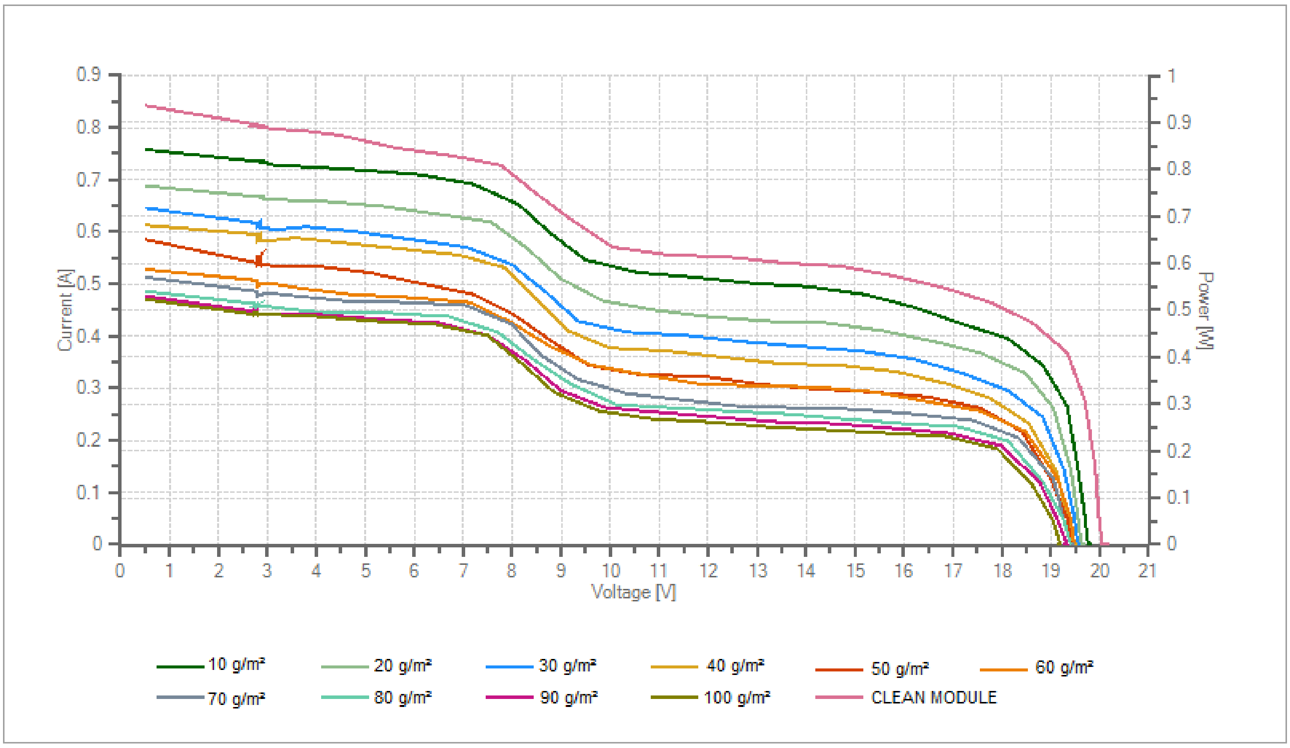

Figure 11: Comparison Outputs of Dust Density Proliferation Experiment

For second and third experiments, the results are illustrated in Figures 12 and 13 respectively. The second series is the reference experiment to investigate the change of dust color brightness from bright (wheat flour) to dark (coffee powder) dust effect as indicated in black color (refer Figure 12). The third experiment is performed to justify the second experiment findings and addition to that a new color tone (yellow) is tested by depositing it on the surface to observe the changes in voltage, current and power (refer Figure 13) with the change of yellow dust tone from bright to dark.

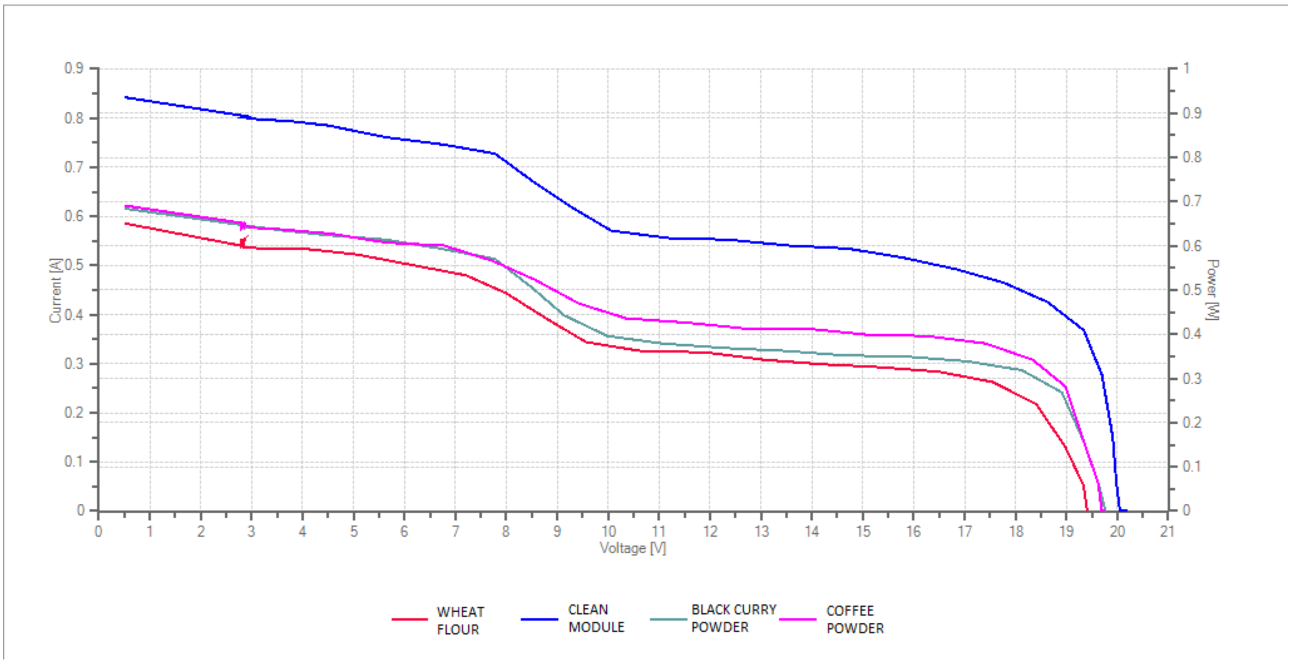

Figure 12: Comparison Outputs of Dust Brightness and Darkness Tone (Reference Experiment)

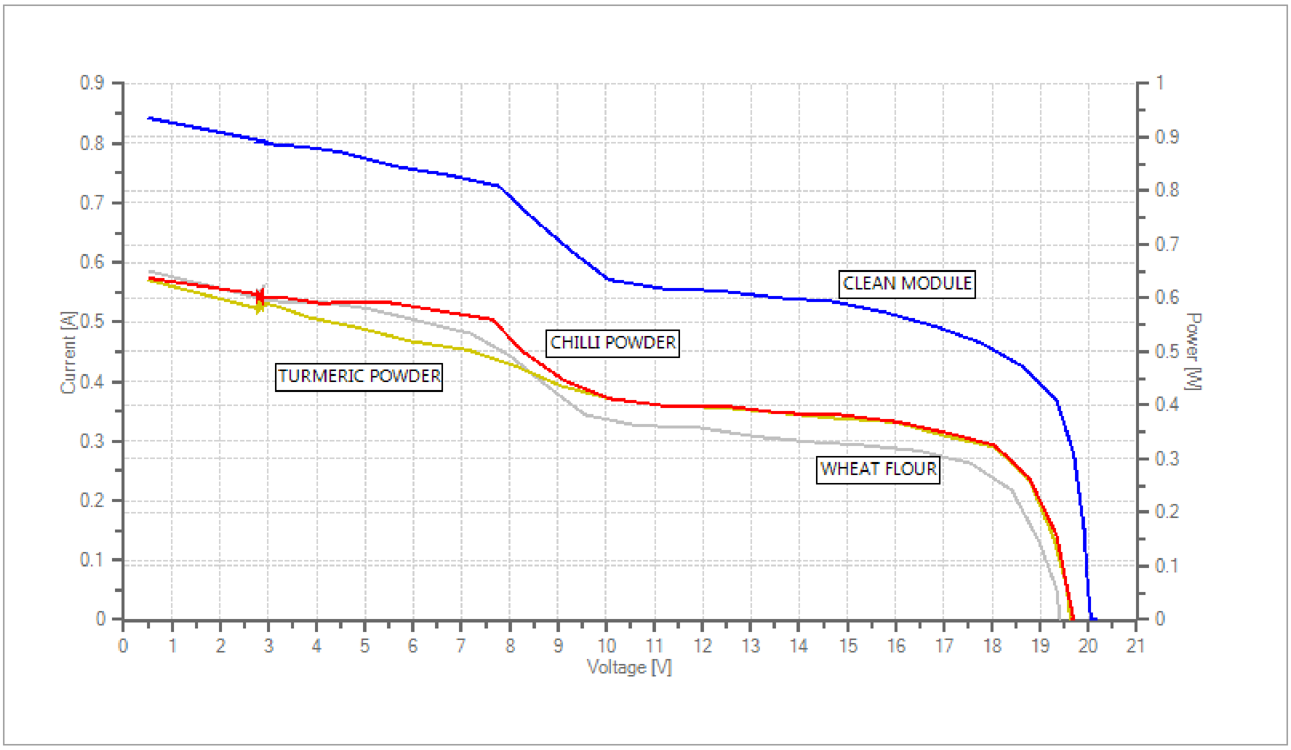

Figure 13: Comparison Outputs of Yellow Dust Colour Tone Variation (Third/Verification Experiment)

It can be observed from both figures, that the dust with brighter toned dust able to reduce PV module output compared to the dust having darker colour tone. The measurements of V_{oc}, I_{sc} and P_{max} of second and third experiments are tabulated in Table 1.

Table 1. Measured outputs (V_{oc}, I_{sc} and Power) for Different Dust Tones Experiments

Color Tone Ranking	Reference				Confirmation			
	Dust Type	P_{max} (W)	V_{oc} (V)	I_{sc} (A)	Dust Type	P_{max} (W)	V_{oc} (V)	I_{sc} (A)
Brighter Colour Tone	Clean module	8.29	20.17	0.84	Clean module	8.29	20.17	0.84
Bright Colour Tone	Wheat flour	4.66 (43.79% reduction)	19.41 (3.77% reduction)	0.59 (29.76% reduction)	Wheat flour	4.66 (43.79% reduction)	19.41 (3.77% reduction)	0.59 (29.76% reduction)
Dark Colour Tone	Black curry powder	5.20 (37.27% reduction)	19.71 (2.28% reduction)	0.62 (26.19% reduction)	Turme-ric	5.31 (35.94% reduction)	19.64 (2.63% reduction)	0.57 (32.14% reduction)
Darker Colour Tone	Coffee powder	5.94 (28.35% reduction)	19.74 (2.13% reduction)	0.62 (26.19% reduction)	Chilli Powder	5.35 (35.46 reduction)	19.68 (2.43% reduction)	0.57 (32.14% reduction)

From Table 1, it can be observed that the dust tones through the arrangement form brightest to darkest has an obvious degradation pattern on the module's V_{oc}, I_{sc} *and* P_{max}. In the reference set and the confirmation set of experiments, P_{max} and V_{oc} were being reduced more by the bright toned dust than the dark toned dust. However, for I_{sc}, it was reduce more by the brightest toned dust according to reference set experiment. Unfortunately, in the confirmation set, it seem like the dark toned dust has reduce more of I_{sc} eachs at 32.14% reduction being compared to wheat flour which is 29.76%. However the different for I_{sc} reduction percentage in the confirmation set is quite small. Overall, the result shows that bright toned dust are more capable in reducing the PV module's output compared to the dark toned dust.

Meanwhile, for dust particle size experiment, smaller dust particle (wheat flour) able to reduce the PV module output compared to bigger dust particles (fine salt and coarse salt) (refer Figure 14). It is observed that wheat flour reduced 43.79 % of the P_{max}, 3.77 % of V_{oc} and 29.76 % of I_{sc} as tabulated in Table 2. Also, it can be seen that the decrease of V_{oc}, I_{sc} and P_{max} is less with fine salt and coarse salt are tested at the same irradiation level and temperature. This is due to the finer dust particle able to fill in the interstitial space of the accumulated dust on the PV module surface area better than the coarser particle. Also, the bigger dust particle if lumped together, there will be interstitial space amongst each other which is bigger than the finer dust particle and allow bigger the light beam penetration to the module surface.

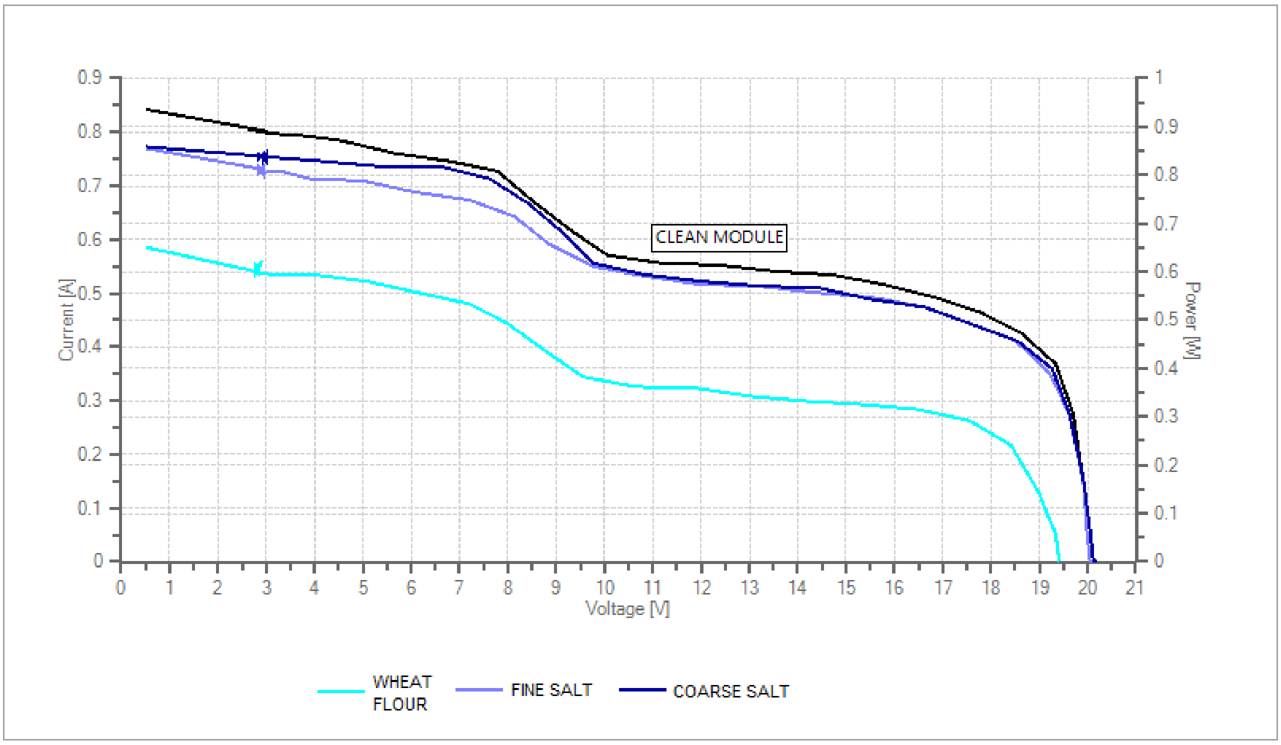

Figure 14: Comparison Outputs of Dust Particle Size Experiment

Table 2. Measured Outputs (V_{oc}, I_{sc} and P_{max}) for Different Dust Particle Size Experiment

Dust Particle Size in Relative	Dust Type	P_{max} (W)	V_{oc} (V)	I_{sc} (A)
	Clean module	8.29	20.17	0.84
Fine Particle Size	Wheat flour	4.66 (43.79 % reduction)	19.41 (3.77 % reduction)	0.59 (29.76 % reduction)
Medium Particle Size	Fine salt	7.88 (7.60 % reduction)	20.12 (0.25 % reduction)	0.77 (8.33 % reduction)
Coarse Particle Size	Coarse salt	7.88 (7.60 % reduction)	20.17 (0.00 % reduction)	0.78 (7.14 % reduction)

4. CONCLUSION

Based on the four series of indoor experiments conducted to investigate the dust physical impact on PV module performance pertaining to dust deposition density, dust colour tone and dust size particle, it is concluded that:

I) Proliferation of dust loading is strongly correlated to absorbance properties of PV module. The acceleration of dust density shows significant reduction of I_{sc} and marginally reduces the module V_{oc}.

II) Dust deposition with brighter colour tone is able to reduce PV module outputs higher compare to the darker colour tone.
III) Smaller dust size particle-has the ability to reduce the PV module outputs more compared to the bigger dust size particle.

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