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Effects of Dust on the Performance of PV Panels

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***Abstract*—**Accumulation of dust from the outdoor environment on the panels of solar photovoltaic (PV) system is natural. There were studies that showed that the accumulated dust can reduce the performance of solar panels, but the results were not clearly quantified. The objective of this research was to study the effects of dust accumulation on the performance of solar PV panels. Experiments were conducted using dust particles on solar panels with a constant-power light source, to determine the resulting electrical power generated and efficiency. It was found from the study that the accumulated dust on the surface of photovoltaic solar panel can reduce the system's efficiency by up to 50%.

***Keywords*—**Dust, Photovoltaic, Solar Energy.

I. Introduction

A Solar photovoltaic (PV) system uses solar cells to convert energy from sun radiation into electricity. The system is made up by one or more panels, a battery, a charge control and the load. Solar PV panels are normally mounted on roofs and wired into a building by an inverter, which converts the direct current energy received from solar panels into alternating current. There are many types of solar PV cells available, which are mainly monocrystalline silicon cells, multi crystalline silicon cells, thick film silicon, and amorphous silicon. The application of solar energy has become wider, with the solar photovoltaic industry's combined global revenue of US$37 billion in 2008 [1].

In Malaysia, the government has recently been promoting the use of renewable energy due to several driving factors, such as the growing imports of oil and unutilized resources of renewable sources, increasing oil prices, and the environmental awareness. In the Tenth Malaysia Plan, it was reported that the nation attracted investments in solar PV manufacturing that was worth RM9.8 billion or about 20% of investments in the electrical and electronics industries [2]. By 2015, the renewable energy capacity is expected to expand to 985 MW, which contributes 5.5 % to Malaysia's total electricity generation mix.

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Located in the equatorial region, Malaysia has an average solar irradiation of 4500 kWh per square meter [3], and thus making it an ideal place for large scale solar power installations. Considering that the country gets an average of 4.5 to 8 hours of sunshine every day, there is huge potential for high solar power generation. At present, the number of solar PV applications in Malaysia is still low. It is generally restricted to rural electrification, street and garden lighting, and telecommunications. The first centralized solar power station was first built in year 2003, in a remote village, Kampung Denai in Rompin on the eastern coast of Peninsular Malaysia [3]. In a recent development, the Tenaga Nasional Bhd (TNB) who is Malaysia's primary electrical power provider launched the development Malaysia's first solar power plant in Putrajaya [4]. At an approximate cost of RM60 million or US$4 million per megawatt, the project signifies a major step in harnessing the use of renewable energy in the country. The project would be expected to enable the operator to understand the system well before embarking into development of plants of bigger scale.

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 [5] for the solar PV module to generate the equivalent amount of energy consumed in its manufacturing processes. One of the contributing factors in the drop of efficiency of solar PV panels in Malaysia as well as in other country is the accumulated dust on the panel. The nature of the problem may vary by geographical locations.

Hottel and Woertz [6] 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%. In a study by Salim et al. [7] into dust accumulation on a solar-village PV system near Riyadh indicated a 32% reduction in performance after eight months. Wakim [8] indicated a reduction in PV power by 17% due to sand accumulation on panels in Kuwait city after six days. Furthermore the study also indicated that the influence of dust on PV performance would be higher in spring and summer than in autumn and winter. An experiment to investigate the effect of aeolian dust deposition on photovoltaic solar cells by Dirk Goosen et. al [9] showed that the deposition of fine aeolian dust particles on the glazing of PV cells significantly affected the performance of such cells. This 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.

Google, one of the world's well-known organizations in the information technology studied the effects of dirt on solar panels of a 1.6 MW solar installation in its Mountain View headquarters in California [10]. The company made a comparison on two different sets of solar panels in Google campus – the flat ones in carports and the tilted ones on roofs. Theoretically, dirt accumulates on top of the flat panels, whereas rain washes away most dirt on the tilted ones and leaves some accumulation in the corners. The Google crew cleaned them up as part of this study, 15 months after the installation of the panels. For the flat panels, the cleaning resulted in doubling of the energy output overnight. However, for the tilted panels, the difference was found to be relatively small. In a different study on the effects of dust on solar PV panel in Palo Alto, California [11], it was reported that the dirt on solar PV panels caused a 2% of current reduction relative to that for clean panels. Like the other reports, these two studies in California did not quantify the amount of dust involved.

In an experiment in Roorkee, India, Garg [12] discovered that dust accumulation on a glass plate tilted at 45° would reduce the transmittance by an average of 8% after an exposure period of 10 days. In a work by Sayigh [13] in Kuwait, it was observed that about 2.5 g/m²/day of dust were collected between April and June. Further investigation [14] on the effect of dust accumulation on the tilted glass plates revealed a reduction in plate-transmittance ranging from 64% to 17%, for tilt angles ranging from 0° to 60° respectively after 38 days of exposure. A reduction of 30% in useful energy gain was observed by the horizontal collector after three days of dust accumulation. In another study that included investigations of the physical properties and deposition density on the performance of solar PV panels by El-Shobokshy and Hussein [15], the artificial dust which included limestone, cement and carbon particulates were used. They used halogen lamps to represent the source of radiation energy. It was revealed in the study that cement particles (at 73 g/m²) would result in the most significant drop in the PV short-circuit voltage; i.e. by 80%. Interestingly, it was found that the smaller the particle size for a fixed deposition density, the greater would be the reduction in solar intensity received by the solar PV panels. This was probably due to the greater ability of finer particles to minimize inter-particle gaps and thus obscuring the light path more than that for larger particles.

In this paper, the influence of dirt accumulation on the efficiency of solar PV panels is assessed by using artificial materials. A constant light radiation condition is used by mean of spotlight to overcome the variation that may be experienced under the sunlight.

II. Experiment Apparatus and Setup

Shown in Figure 1 is schematic of the experiment rig. Basically the system comprised a solar photovoltaic panel (rated 50 W), as shown in Figure 2, a set of spotlight and the electrical circuit system. The solar panel module was made up of silicon mono-crystal cells; each cell had an area of 10 cm². The dimensions of the panel were 1004 mm by 448 mm by 43 mm. The system was installed in an indoor lab and the radiation energy was delivered by the spotlight system, each rated at 500W. The number of spotlights and their positions could be varied depending on the requirements of experiments. To measure irradiation on the solar panel, a HD2302 Delta OHM photo-radiometer was used. For the measurements of voltage and current, Sanwa YX360TRF analogue multimeters were used in the arrangement as illustrated in Figure 1. The system's load was simulated by using different resistors.

Experiments were performed by applying artificial dusts on a layer of plastic sheet, prior to placing the set onto the solar PV panel. Tests were conducted also with the clean plastic sheet and with bare panel in order to quantify the effects of dust on the performance of the PV panel. In each condition, the distance between the spotlight and solar PV panel was varied in order to develop the current-voltage characteristics of the panel. The decision on the appropriate number of spotlights is described in the next section.

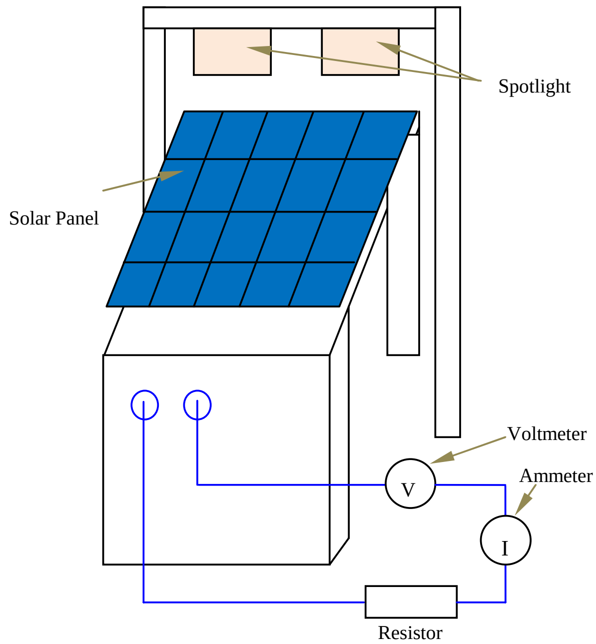

Fig. 1 Schematic of the system

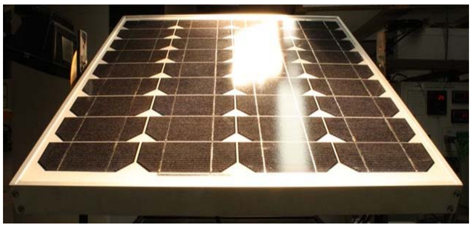

Fig. 2 The solar photovoltaic panel

In this project, two types of artificial dust; i.e. dried mud and talcum powder, were used instead of real dust to represent the dust accumulation. The use of natural dust accumulation was avoided because it might not be well distributed on the surface of solar PV panel, since it would be exposed naturally to the environment and the dust settlement could be subjected to the wind effect. Such non-uniformity might be neutral but it would complicate study of the fundamental aspect of the dust effect.

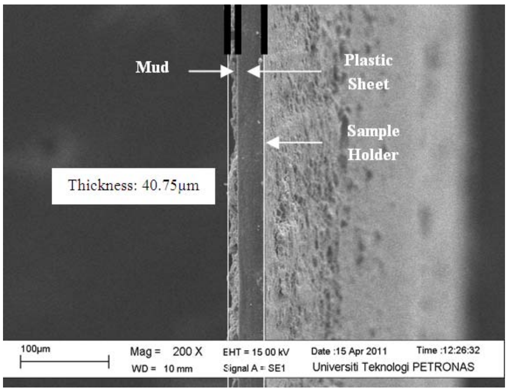

Fig. 3 SEM image for thickness of mud layer

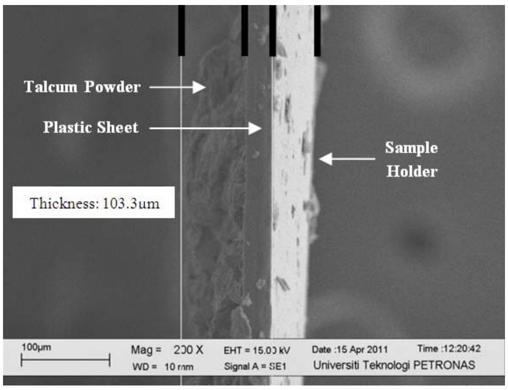

Fig. 4 SEM image for thickness of talcum powder layer

In order to quantify the thickness of the dust layer, a clear plastic sheet was placed on the solar panel for surface protection. The artificial dust was prepared by distributing the particles evenly on the plastic sheet. In order to measure the thickness of the dust layer, a tiny portion of the plastic sheet (with dust on it) was cut and was sent to the laboratory for measurement using the Scanning Electron Microscope (SEM). All experiments were executed by measuring the output voltage and current produced by solar PV. Clean solar panel without plastic covering its surface was chosen as true control. The experiment is then continued using three different plastic sheets to represent different conditions of dust accumulation on the surface of solar panel.

Shown in Figures 3 and 4 are images of the cross-section of the artificial dust layers and plastic sheets obtained using the Scanning Electron Microscope at 200× magnification. The thickness of the clear plastic sheet was 28 µm as measured in both figures. The average thickness of the dry mud layer is found to be about 41 µm, and about 103 µm for the talcum powder layer. Although the dust was spread evenly on the plastic sheet, the thickness seemed to be varied when examined through the SEM. Therefore, approximation was made in judging the average thickness of the dust layers.

III. Identification of Optimum Height of Lamps

Shown in Figure 5 is the variation of the irradiation measured on the panel with distance between the light source and the surface of PV solar panel, with the use of only one spotlight. Three measurements were taken at different positions on the panel to check the distribution of irradiation. Reading 1 was taken at the centre of solar PV panel, and Reading 2 and Reading 3 were obtained 5 cm and 10 cm away from the centre, respectively.

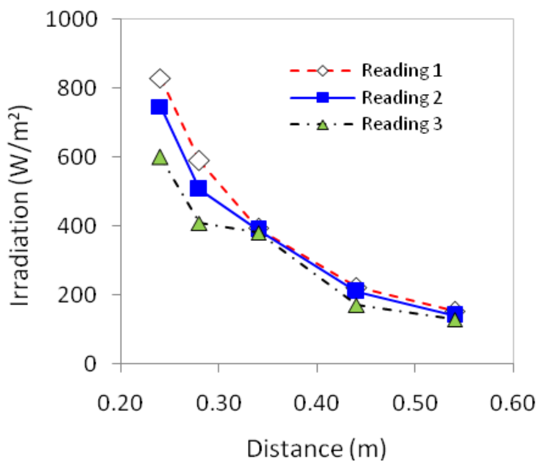

Fig. 5 Irradiation versus distance for one spotlight

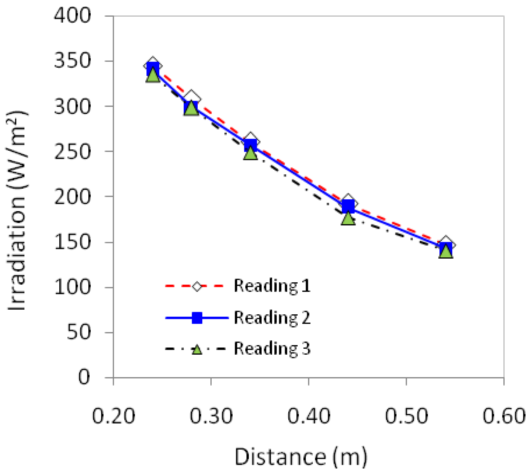

Fig. 6 Irradiation versus distance for two spotlights

In Figure 5 the radiation intensity from the light is shown to be the highest when the distance from PV solar cell is the smallest, and vice versa. The results are shown to be repeatable but there is a relatively significant scatter in the results when the distance between the lamp and the panel is the nearest.

The same experiments were repeated but with the use of two spotlights and the results are shown in Figure 6. It is shown from the figure that the results are highly repeatable when two spotlights are used in comparison to that using only one spotlight. Thus, it implied that the use of two spotlights would be preferred in the study, as it would be able to resemble close to the real condition in which the sun's radiation intensity would be well distributed over a small area (i.e. the panel). In general the trend of variation in results of Figure 7 is similar to that in Figure 6; i.e. irradiation is inversely proportional with distance between the light source and the panel. Fig. 6 reveals a pattern of incoming solar energy at different distances from the sun.

The larger scatter among the measurements in Figure 5 relative to that in Figure 7 shows that the resulting irradiation on the solar panel by using one spotlight was not well distributed, and hence the use of two spotlights would be a better option. Therefore, the experiments were using two spotlights as the source of radiation heat. The distances between the lamps and the panel for the experiments were set to be 240 mm, 280 mm and 340 mm, which correlated to irradiation values of 340 W/m^2, 301 W/m^2, and 255 W/m^2, respectively.

IV. Results and Discussions

A. Voltage –Current Characteristics

Shown in Figures 7 to 9 are the current-voltage or *I-V* curves for solar PV panels in all conditions: clear plastic sheet, plastic coated with mud, plastic coated with talcum powder, and solar PV without any plastic sheet for different irradiation values. The solar PV panel produced a maximum power of 4.25 W as recorded for the clear plastic sheet and solar PV panel without plastic. The maximum voltage measured was 18 V.

For irradiation of 255 W/m², and 301 W/m², the curve for all four conditions are quite close to each other, in which the differences among them are not significant. However when the experiment was conducted at irradiation of 340 W/m², the curve for plastic coated with talcum powder seems to have a significant difference compared to the other three conditions. This was probably due to the effects of dust accumulation on it which was far more effective in obstructing the light from hit the surface of the solar PV panel.

In general the trend of current-voltage characteristics is shown to be similar with that of typical solar panels. Since the area under the curve would represent the electrical power of the solar PV system, it can be summarized from the graphs that the highest power could be produced when the panel is not covered by layer of dust or plastic. With the introduction of dusts, the area within the curve becomes smaller, implying the reduction in energy generated. The peak power, which is normally represented by the top corner point of the curve, also shows the same trend of reduction due to the presence of dust.

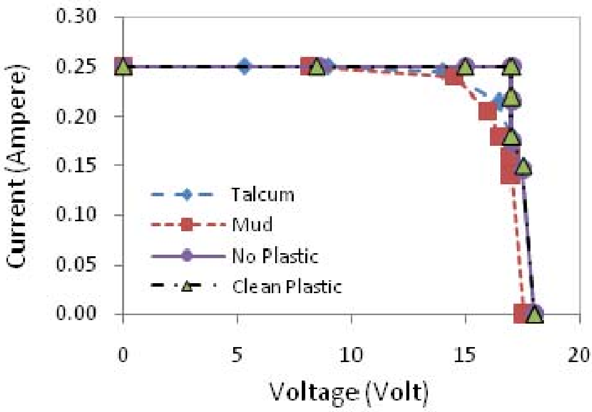

Fig. 7 *I-V* characteristics for irradiation of 255 W/m^2

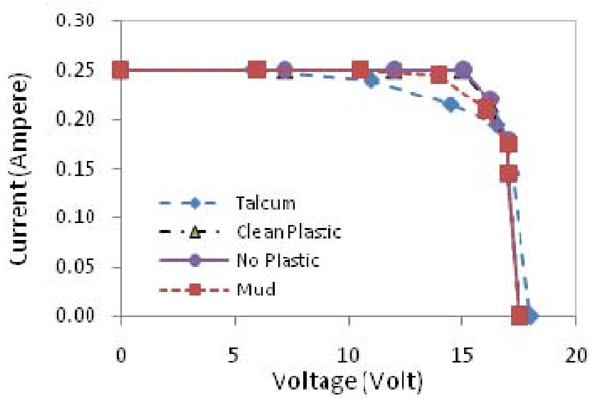

Fig. 8 *I-V* characteristics for irradiation of 301 W/m^2

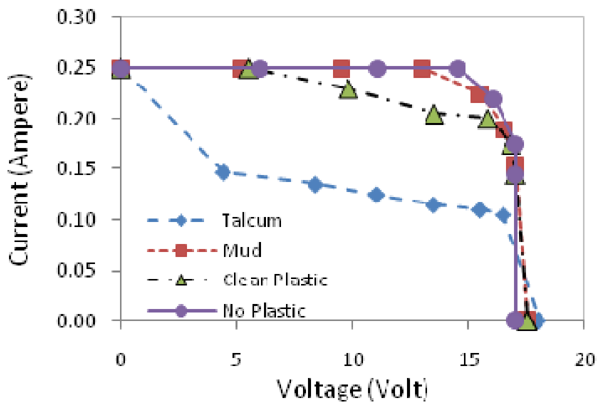

Fig. 9 *I-V* characteristics for irradiation of 340 W/m^2

B. Effect of Dust on Peak Power and Efficiency

The effect of dust on the panel is quantified by tabulating the peak powers of the solar PV panel under each experiment condition. Shown in Table I are the values of peak powers for different conditions of panel's surface and irradiation value. The peak powers were obtained from calculations using the measured values of current and voltages.

TABLE I
PEAK POWER FOR DIFFERENT CONDITIONS ON THE PV PANEL

Condition	Peak power (W)		
	255 W/m²	*301 W/m²*	*340 W/m²*
No plastic	4.25	4.12	3.62
Clean plastic	4.25	3.75	3.16
Mud	3.48	3.43	3.49
Talcum	3.55	3.22	1.73

It is shown in Table I that the highest peak power occurred when the panel was not covered. The clean plastic reduces the peak power slightly except for the case of 340 W/m² of irradiation and further investigation would be suggested in the future. The cause for this is not well understood. If the results using irradiation of 340 W/m² were to be excluded, the reduction caused by the mud layer was found to be as high as 18.1%; i.e. under the lowest irradiation. Talcum powder exhibited almost the same reduction; i.e. a maximum of 16.5%. In general the trend is the effect of the presence of dust is less significant under high irradiation condition. The lowest reduction was 3.6%, for mud at irradiation level of 340 W/m².

To determine efficiency of the solar panel, the equation is given by [16]:

$$\eta = \frac{V_p I_p}{P_s A} \times 100\% \qquad (1)$$

where I_p is the electrical current produced by the solar PV panel, V_p is the voltage of the electricity produced, P_s is the power of the incident solar radiation (W/m²), and A is the exposed area of the solar cell. It must be noted though that Eqn. (1) is intended for use under standard test condition; i.e. under a temperature of 25°C and an irradiance of 1000 W/m² with an air mass 1.5 (AM1.5) spectrum. In the present work, the required irradiance was not met, but the calculation of efficiency was meant as an indicator for comparison between the different conditions of solar panel surface.

The highest calculated efficiency for the clean plastic is 4.82%, plastic coated with mud is observed to be 3.95%, plastic coated with talcum powder is observed to be 4.03%, and for solar PV panel without plastic is observed to be 4.82%. This clearly shows that clean plastic and solar PV panel without plastic gives the highest efficiency due to the absence of dust on its surface.

V. CONCLUSIONS

The effect of presence of dust was studied using artificial dust (mud and talcum) under a constant irradiance conducted in an indoor lab. Dust has an effect on the performance of solar PV panel. The reduction in the peak power generated can be up to 18%. It was also shown that under greater irradiation, the effect of dust became slightly reduced but not negligible. In the study, it was also shown that the differences between the results obtained by using mud and talcum were generally small; i.e. about 6%. Hence, in practice, dust must be removed from the surface of solar PV panel in order to ensure highest performance, given the fact that it is still a costly form of energy source and the short lifespan it has.

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REFERENCES

[1] Solar Power Information (2009, 8 April 2011). *Solar Panels.* Available: www.solarpower2day.net/solar-panels/.
[2] "Tenth Malaysia Plan: 2011-2015," Economic Planning Unit, Putrajaya, 2010.
[3] S. Sriram. Frost & Sullivan (2006, 8 March 2011). *Solar Power in Malaysia - Impediments to Growth.* Available: www.frost.com/prod/servlet/market-insight-top.pag?docid=67575287.
[4] A. Gabriel. Malaysia's First Solar Power Plant, 23 February 2011, The Star Online, http://biz.thestar.com.my/.
[5] R. Kannan, K. C. Leong, R. Osman, H. K. Ho, and C. P. Tso, "Life cycle assessment study of solar PV systems: An example of a 2.7 kWp distributed solar PV system in Singapore," *Solar Energy*, vol. 80, pp. 555-563, 2006.
[6] M. C. Hottel and B. B. Woertz, "Performance of flat plate solar heat collectors," *ASME Trans.*, vol. 64, pp. 91-104, 1942.
[7] A. Salim, F. Huraib, and N. Eugenio, " PV power-study of system options and optimization," in *Proceedings of the 8th European PV Solar Energy Conference*, Florence, Italy, 1988.
[8] F. Wakim, "Introduction of PV power generation to Kuwait," Kuwait Institute for Scientific Researchers, Kuwait City, 1981.
[9] D. Goossens and E. V. Kerschaever, "Aeolian dust deposition on photovoltaic solar cells: the effects of wind velocity and airborne dust concentration on cell performance," *Solar Energy*, vol. 66, pp. 277-289, 1999.

[10] M. Moon. (2009) Google Studies How Dirt Affects Solar Panel Efficiency. *PC Magazine: Good Clean Tech*. Available: www.goodcleantech.com/2009/08/google_studies_how_dirt_affect.php.
[11] G. B. Katz. (2008, 27 April 2011). *Effect of Dust on Solar Panels*. Available: www.gregorybkatz.com/Home/effect-of-dust-on-solar-panels.
[12] H. P. Garg, "Effect of dirt on transparent covers in flat-plate solar energy collectors," *Solar Energy*, vol. 15, pp. 299-302, 1973.
[13] A. A. M. Sayigh, "Effect of dust on flat plate collectors," in *Proceedings of the International Solar Energy Congress*, New Delhi, pp. 960-964, 1978.
[14] A. A. M. Sayigh, S. Al-Jandal, and H. Ahmed, "Dust effect on solar flat surfaces devices in Kuwait," in *Proceedings of the Workshop on the Physics of Non-Conventional Energy Sources and Materials Science for Energy*, Triest, Italy, pp. 353–367, 1985.
[15] M. S. El-Shobokshy and F. M. Hussein, "Degradation of photovoltaic cell performance due to dust deposition on to its surface," *Renew Energy*, vol. 3, pp. 585–590, 1993.
[16] ASTM, "ASTM G 173-03: Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface," ed: ASTM International, 2003.