Experimental investigation of impact of dust accumulation on
the performance of photovoltaic solar module

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Abstract. The effect of dust and sand on the surface of photovoltaic module has been
investigated experimentally in this paper. The size distribution analysis of each sample was
carried out using digital microscope. The chemical composition was investigated through EDX
analysis. Experiments on photovoltaic solar module were conducted under controlled conditions
by using artificial light source at different tilt angles and a dust blower. It has been concluded
that there was only a small difference of degradation in maximum voltage and current when dust
and sand was deposited on photovoltaic panel. The voltage decrement was 9.1%, 3.1%,
1.2% and 6.1% at tilt angles of 35°, 45°, 55° and 65°, respectively. These results reveal that the solar
panel should be installed at angles between 45° and 55° in order to minimize the dust impact.

1. Introduction
The demand of sustainable and clean sources of energy is increasing every day. Solar photovoltaic (PV)
ergy has become the great concern of achieving electricity due to its several advantages over other
energy sources. It proves green energy with no carbon emission, which is its main advantage and it is
environment-friendly source of clean energy. According to a report, about 232 MWp energy from new
solar modules was gained by the Chinese consumers until 2012. The Chinese government is planning to
enhance this capacity to 1800 MWp in 2020. There are a lot of factors like humidity, soiling and wind
velocity, tilt angle, mismatch of array and efficiency of inverter that effect the adeptness of solar
modules. The impact of dust on performance of solar PV is of great concern. The significant impact of
weather, dust and location may degrade the solar PV efficiency. Besides that, the size of dust and
surrounding condition also have great influence on output power of modules. El-Shobokshy and Hussein
[1] examined that smaller particles cover the solar cell more densely than larger particles. Many studies
on this problem confirmed that high concentration of airborne dust on open-air PV installation degrade
the cell glazing transmittance. This factor became the root of substantial reduction in efficiency of PV
modules.

Nahar and Gupta [2] conducted some experiments in Thar desert (India) to examine the influence
doing dust on different glazing surfaces and measure their transmittance. They observed that by increasing
the tilt angles from horizontal position, the dust resolution decreases. They found 19.17%, 13.81% and
5.67% depletion in transmittance of glass surface at different tilt angles. The transmittance was also
decreased significantly with increasing the tilt angle. El-Shobokshy and Hussein [1] measured energy
output of solar cells under zero wind condition by polluting solar panel surfaces with different dust types. The result concluded that effect of dust might be not further associated to the exposure time and fine particles has greater impact than large particles [3]. It was revealed that dust type, dust size and density of dust accumulation cause a reduction in energy efficiency of PV solar panels. El-Nashar et al. [4] observed the impact of dust deposition on the efficiency of solar collectors in United Arab Emirates for different periods. The result revealed that the monthly glass transmissivity decline rate was between 6% to 10%, depending on season. Hottel and Wortz [5] conducted 90 days trial on performance of solar collectors at a fixed tilt angle of 30. The net performance of collector was decreased by 4.7%. The effect of dust was not so significant because collector remained cleaned due to frequent rainfall.

El Hamdani et al. [6] observed that the effect of dust deposition on solar PV modules is more pronounced for fine particles than large particles. Elminir et al. [7] examined the impact of dust on solar collectors having transparent cover by using hundred samples of glasses and concluded that at tilt angles of 0° to 90°, the transmittance decreases from 52.54% to 12.38%. The decline rate of transmittance is affected by dust deposition density. According to Mejia et al. [8], the decrease in performance of solar photovoltaic system is due to dust deposition is 7.4% for 145 days in summer season. Sulaiman et al. [9] studied the impact of dust by using different impediment materials on efficiency of photovoltaic panels and concluded that the outdoor elements decrease the solar performance up to 85%. Alwaeli et al. [10] observed almost 50% of reduction in performance of photovoltaic modules installed in Baghdad city of Iraq. They revealed that the thickness of dust increases and amount of transmittance decreases over specific period of time [10-14].

Therefore, the purpose of this research paper is to investigate current and voltage response to dust and sand which accumulated on surface of photovoltaic module for a specific time period. The experiment was conducted under controlled conditions at different tilt angles.

2. Materials and methods

The experiment was conducted under controlled conditions in plasma physics laboratory at university of Agriculture, Faisalabad, Pakistan. Figure 1 shows schematic of the experimental arrangement. A 30 W polycrystalline PV module was placed under an artificial lighting source, comprising of two filament tungsten bulbs each of 100 W. An artificial lighting setup was used to avoid inconsistency in solar radiation. A high precision digital multimeter was used to record current and voltage of PV module. Four digital thermometers were used to monitor the surface temperature at different points on the module. A dust generator was used to blow the module with dust and sand samples at different tilt angles.

The specification of solar PV module is summarized in table 1. Firstly, the solar panel was installed at four different angles of 35°, 45°, 55° and 65°. A stand was placed behind the module on which two filament tungsten bulbs were fixed by using nails. Two unit of 100 W bulbs were used as light source. A dust generator was fixed at 4 feet from the panel. The dust and sand were uniformly spread over module surface in separate experiments. The solar panel was divided into four sections and the temperature of each section was monitored using digital thermometers. Each experiment conducted for 60 minutes of duration and data were taken for five minutes interval. The flowrate was fixed at 500 g/h.
Figure 1. Schematic of experimental setup.

Table 1. Specifications of PV module.

| Parameter                        | Value           |
|----------------------------------|-----------------|
| Solar module type                | BCT30-12        |
| Peak power (pm)                  | 30 W            |
| Maximum power current (I_{mp})  | 1.83 A          |
| Maximum power voltage (V_{mp})  | 16.4 V          |
| Short circuit current (I_{sc})   | 1.98 A          |
| Open circuit voltage (V_{oc})    | 21.6 V          |
| Dimensions                       | 660×408×25 mm³  |

3. Results and discussion

The surface of panel was simulated for dusty surface by falling sample of dust and sand applied on the surface. In order to create the reference dust, the samples of dust and sand were prepared specifically for this work. Dust was collected from the agricultural field of Ghulam Muhammad Abad, Faisalabad and sand from the local building material shop. The samples were analysed for their surface morphology and particle size through a digital microscope. The obtained images were analysed to observe the nature and size distribution of sample particles. Chemical composition was also determined through EDX. The magnified images of dust and sand samples are shown in figure 2. The results show that the size of the samples remained between 62 µm and 128 µm.

Figure 3 shows the trend of temperature over time. The surface temperature remained unchanged over time. Since artificial light source was used to illuminate the PV module, the light intensity did not change over time and consequently the temperature. A comparison of average temperature for different tilt angles reveals no effect of angle on surface temperature under artificial lightening. Some variations in temperature were observed during early stage of the experiment, thereafter temperature become stable over time. Even dust accumulation did not affect the surface temperature. Similar temperature results were reported for both sand and dust accumulations.
Figure 2. Image of dust (a, b) and sand (c, d) samples.

Figure 3. Average surface temperature as a function of time for different tilt angles.

Figure 4 and figure 5 show module voltage as a function of time at different tilt angles for both dust and sand. A degradation of the voltage was observed with time due to increment in dust layer thickness and tilt angle. For dust and sand, voltage was decreased by 2.5 V and 0.5 V respectively, with an increase in tilt angles. Similarly, voltage was decrease by 0.7 V and 2.5 V after 60 minutes of continuous dust and sand bombardment. It reveals that tilt angle is more important during dust accumulation and test time during sand accumulation.
Figure 4. Voltage as a function of dust accumulation time for different tilt angles.

Figure 5. Voltage as a function of sand accumulation time for different tilt angles.

Figure 6 and 7 show current as a function of time at different tilt angles for both dust and sand. The current revealed a decreasing trend with tilt angle for both dust and sand. The current was decreased by 40 mA in dust environment and 35 mA in sand environment with an increase in tilt angle from 35° to 65°. For dust dominated environment, tilt angle of 35° to 45° is recommended for PV modules. For sand dominated environment, tilt angle of 45° to 55° is recommended for PV modules. There was no effect of exposure time on current was observed in the presented study. The current remained almost constant over time. These results were generated for fixed exposure time dust/sand flowrate. The presented results may vary with change exposure time and flowrate. The effect of these parameters on the performance of PV modules will be considered in future work.
Figure 6. Current as a function of dust accumulation time for different tilt angles.

Figure 7. Current as a function of sand accumulation time for different tilt angles.

4. Conclusion
In this study, the impact of dust on performance of photovoltaic module has been investigated at different angles under constant artificial light source. Some variations in surface temperature were observed during early stage of the experiment, thereafter temperature become stable over time. The dust and sand accumulation did not affect the surface temperature. For condition of dust and sand, the voltage was decreased by 2.5 V and 0.5 V, respectively with an increase in the tilt angle. Similarly, voltage was decrease by 0.7 V and 2.5 V after 60 minutes of continuous dust and sand bombardment. It has been found that the tilt angle is more important during dust accumulation and test time during sand accumulation. For dust dominated environment, tilt angle of 35° to 45° is recommended for PV modules. Meanwhile, for sand dominated environment, tilt angle of 45° to 55° is recommended for PV modules.

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