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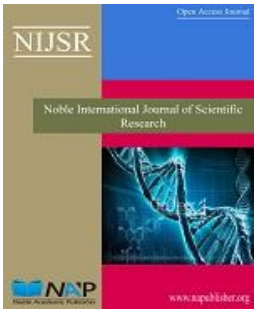

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Effect of Dust on the Performance of Photovoltaic System (A Case Study of Quaid-E-Azam Solar Park Bahawalpur, Pakistan)

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Abstract: The process of transfer of radiation from the shining surface of the photovoltaic module is adversely affected by the accumulation of dust carried by air. This research work is directed to investigate the effect of the dust particles accumulated on the surface of polycrystalline photovoltaic modules. In this research two polycrystalline modules were used by the string equipped with twenty (20) and out of those two modules, one was exposed for three months of summer season in natural atmosphere with regular cleaning at Quaid-e-Azam Bahawalpur Park, Pakistan. During this period, a series of systematic measurements related to different densities were performed. This study shows that a noticeable difference was seen between the different parameters of production of both clean and dirty modules. This study also provides information about percentage loss for different densities of dust. The densities of dust accumulated on the surface of the PV module for June, July and August were 0.786 mg / cm2, 0.681 mg / cm2 and 0.601 mg / cm2 respectively. The results obtained from this study show that accumulation of dust has strong effects on the performance of PV modules. These results also show that average output power of polycrystalline modules used in this study is 19% less as compared to pure-type modules of the same type. It was estimated that the modulating efficiency of the module (ή clean - ή dirty) for the polycrystalline module was 3%. Moreover, it is concluded that dust has a great impact on the power and efficiency of the photovoltaic module production.

Keywords: Photovoltaic Modules, Polycrystalline, Solar Cell, Power Reduction, Efficiency Reduction, Outdoor Evaluation.

1. Introduction

Contemporary, renewable energy related features are becoming very important for developing countries. They involve for example, a rational use of resources, the climatic impact relevant to the pollutants emission and the consumption of non-renewable resources. For these reasons the world is gradually moving towards the production of energy from renewable energy resources. Among the recent modern technologies like photovoltaic (PV) cells, wind generators , biomass plants and fuel cell technology that could play a very important role in the generation of sustainable and prevalent energy. The photovoltaic technology can be considered one of the most extensive solutions with significant margins of improvement while ensuring the generation of energy with no environmental impacts. Photovoltaic module receives light energy from solar irradiance and converts it directly into electricity. The performance of PV modules depends upon the geographical parameters (latitude, longitude, and intensity of solar irradiance), the climatic factors (rain, wind, temperature, relative humidity, pollution, dust, etc.) and the type of PV technology used [1]. The previous researches show that the PV modules behave differently in different specific climatic conditions. Similarly, the research activity and development in the PV field has usually been focused on solar irradiance analysis, efficient operating strategies, design and size of these systems. Even many researchers have analyzed the PV module in terms of panel modeling and I-V characteristic. But the manufacturers do not involve the critical aspects and external conditions of PV module into considerations.

Bashir, et al. [2] exploring the performance of three locally available PV modules in the winter conditions of Taxila, Punjab, Pakistan. The mono crystalline PV module showed the highest efficiency of the module. He noticed that the production of PV modules depends upon solar radiation and temperature of module. Kaldellis, et al. [3] investigated the effect of dust on the PV modules and found that the

efficiency of the PV module was reduced to 0.4% when the density of the dust increased to 0.09 mg/cm^2. Rajput and Sudhakar [4] studying the behavior of PV modules with deposited dust on their surfaces. The results showed that power and efficiency of the PV module decreased to 92% and 89% respectively as compared to clean modules. Jiang, et al. [5] investigated the influence of dust deposition in the air on the performance of the PV module within the laboratory under controlled conditions in a test chamber. Dust was uniformly distributed on the surface of the panel with the help of a fan. It was found that the efficiency of the PV module was reduced to 26% as the mass of the dust increased to 22g/m^2. Adinoyi and Said [6] discovered the dust effect on the performance of PV modules in Saudi Arabia. After six months of exposure to the natural environment, a power reduction of 50% was considered in the PV modules. Similarly, Cabanillas and Munguia [7] found that with the increase of dust to 2.326 mg/cm2 in 20 days, the reduction in power was 6% for crystalline silicon module and 13% for amorphous silicon module. Kumar, et al. [8] determined dust impact on the performance of PV modules by conducting experiment on a photovoltaic panel of dimensions 9 cm2 with a maximum power of 302 MW. It was found that the reduction of energy transformation efficiency was 10%, 16% and 20% with the density increase of 0.1g, 0.2g, 0.3g respectively. Mohamed and Hasan [9] examined the accumulation of dust on the surface of 4 poly-crystalline modules and found a 50% efficiency reduction in PV module.

Benatiallah, et al. [10] and Bouchalkha [11] also reported that output power of the module decreases by increasing the density of dust on the surface of the PV modules. From the above literature it can be concluded that the deposition of dust on the surface of the PV module has a major effect on reducing the output power and should not be neglected in the measurement of the module performance. EI-Shobokshy and Hussein [12] used five types of dust that have different properties. Three of them were limestone particles of different grades and the other two were cement and carbon particles. The effect of particle size was investigated and revealed that thin particle dust has a greater impact on the PV module performance than the toughest particles. Shaharin, et al. [13] investigated that the PV system's performance and the accumulated dust effects are limited since the dust is a complex phenomenon that is affected by various environmental and atmospheric conditions.

This current study investigates the effect of dust on photovoltaic module performance at Quaid-e-Azam Solar Park Bahawalpur, Punjab, Pakistan. As Bahawalpur is associated with the Cholistan desert, that's why the effect of dust on PV modules cannot be ignored.

2. Methodology and Experimental Setup

The dust effect was investigated using two polycrystalline photovoltaic modules available at the market. Both are made by JA solar with a capacity of 255 watts each. The modules were placed on the ground at Quaid-e-Azam Solar Park, Bahawalpur, Punjab, Pakistan on a shelf faces southward at a fixed angle of 28oC in figure 1. The estimated power rating by manufacturer for each four-lac module with cost 150 million US dollars was 255 watts. Manufacturers estimated module values are expressed in Table 1. The measured values in the zone area are shown in Table 2. Similarly, Figures 2 and 3 show the dust collections in the PV modules and the dust removed from the PV modules.

Figure 1. Dust depositions on PV modules

Figure 2. Dust accumulations on PV modules

Figure 3. Dust removed PV modules

Table 1. Modules dimensions and rated values at STC

Specifications	**p-Si**
Modules Dimensions	
Modules dimensions (L*W*H) (mm)	1650*991*40
Cell dimensions [mm*mm]	156×156
Total no. of cells in series	6×10
Total area of cells (m^2)	1.460
Rated Values at STC	
Maximum power, P_{max} [W]	255
Maximum module efficiency [%]	15.59
Maximum current, I_{max} [Amp]	8.42
Maximum voltage, V_{max} [V]	30.29
Short circuit current, I_{sc} [Amp]	8.98
Open circuit voltage, V_{oc} [V]	37.82

Source: Data collection from Quaid-E-Azam Solar Park Bahawalpur

Table 2. Avg. measured values of three months

Measured values	**Clean**	**Dirty**
Avg. solar irradiance [W/m2]	694.6	694.563
Avg. module power [W]	135.4	116.7
Avg. module efficiency [%]	13.32	10.87

Source: Data collection from Quaid-E-Azam Solar Park Bahawalpur

During the study, the two polycrystalline type modules remained in an external environment were regularly cleaned to measure the correct values. And on the other side of the second module, the current and voltage values are measured with dust. After receiving all the values for the duration of power and three-month efficiency are calculated. The dust effect is determined by comparing the parameters of the output of clean and dirty modules. Density of dust is measured by weighing the dust accumulated on the glass sheet placed next to the module using the digital weight balance. The difference between the weight before and after the dust accumulated on the sheet provided information on the density of dust deposited in the module area. The dry factor also affects the night, while all PV modules are kept in an open, unprotected environment managed at night. Voltage and current measured by QASP staff, secondary data

collected in site are used here. Maximum power is calculated using the maximum measured current and maximum voltage.

$$P_{max} = V_{max} * I_{max} \quad (1)$$

The device called pyranometer was used to measure the solar irradiance; the cumulative average measured values of solar radiation for three month were 694.6 W/m^2. Similarly, each individual month has a median measured value, June (758.3 W/m^2), July (710.1 W/m^2), August (615.8 W/m^2). The following relation is used to calculate the efficiency of the PV modules

$$\eta = (P \text{ max}) / (S.I*A) * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

% Reduction in output power

$$= (P \text{ clean} - P \text{ dirty}) / (P \text{ clean}) * 100 \quad \ldots\ldots\ldots\ldots (3)$$

% Reduction in module efficiency

$$= (\eta \text{ clean} - \eta \text{ dirty}) / (\eta \text{ clean}) * 100 \quad \ldots\ldots\ldots\ldots (4)$$

Block dust and sunlight spread to reach the cells. Block expansion depends on the type and degree of accumulation on the surface of the panel. Just as many people have done research and said the dust deposition effects are limited since dust is a complex phenomenon that is affected by various environmental and climatic conditions. An airborne dust sample was collected and tested to find the powder composition in the Ayub laboratory for soil and water analysis Bahawalpur. There was 71% fine sand (diameter> 0.06 mm), 18% silt (diameter 0.06-0.002 mm) and 11% clay (diameter <0.002 mm).

3. Results and Discussion

Air dust deposited on the surface of the PV module affects the transmission of solar radiation from polishing the PV module area. The result is the significant decline of output power and module conversion efficiency. Figure 4 shows solar radiation of three month in this experimental work at the Quaid-e-Azam solar park, Bahawalpur. The solar irradiance captured by the PV module in June is higher than the other months so the system efficiency is higher in this month compared to the other months.

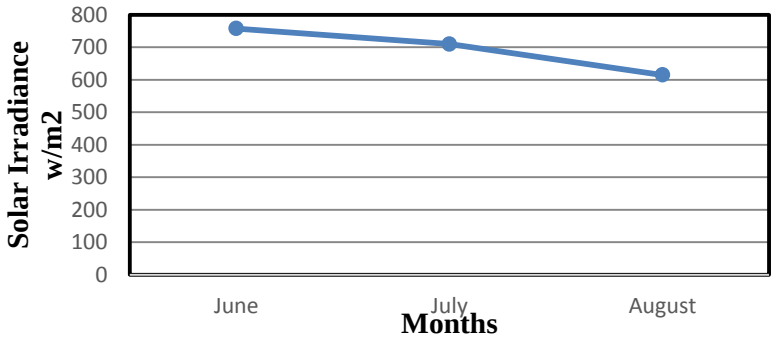

Figure 4. Monthly average solar irradiances

3.1. Effect of Dust on the Output Power of Polycrystalline PV Module

The power output of the photovoltaic modules varies linearly with solar radiation. During the study period, the output power of the modules has continuously decreased due to dust accumulation. As the dust layer on the surface of photovoltaic module has become thicker, loss of power output and module efficiency was higher. The density of the dust accumulated on the surface of the PV module was 0.786 mg /cm^2 for the month of June and similarly for July and August were 0.681 mg/cm^2, 0.601 mg/cm^2 respectively at the end of the study. Initially, after one month the two modules (pure and dirty) showed a slight change in output power, in June the difference is 22% and similar for July and August the difference is 15.5% & 10.2% for polycrystalline PV modules. Over time, the output power of the PV module has gradually reduced compared to the PV module due to the dust deposition on its surface. Similar moderate power reduction trends can be shown respectively in Figures 5, 6 and 7.

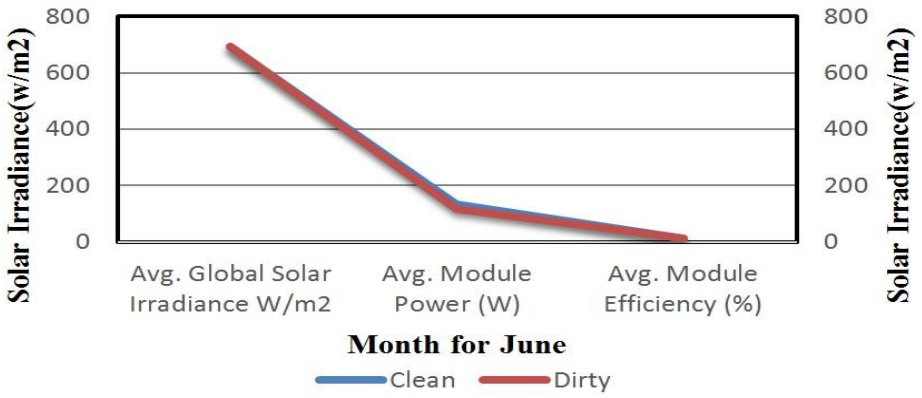

Figure 5. Avg. measured values of months for polycrystalline module (2016)

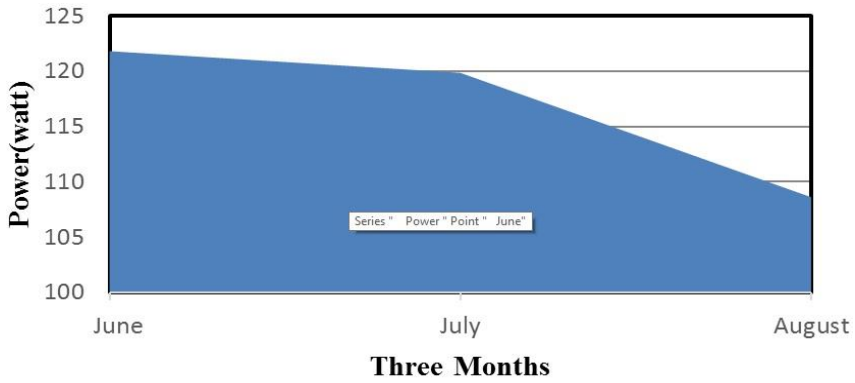

Figure 6. Variation of monthly average power for dirty polycrystalline PV module

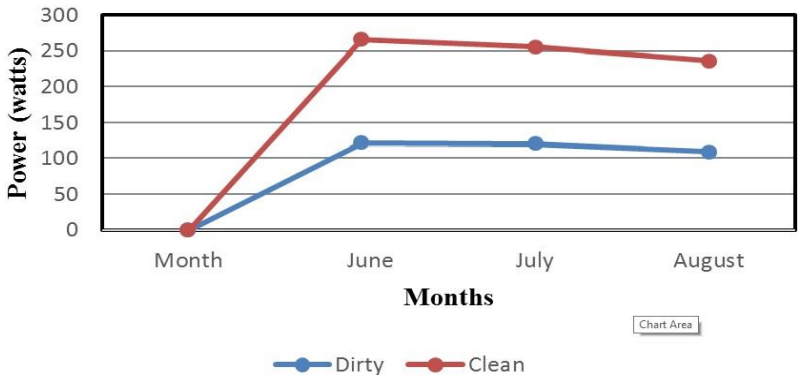

Figure 7. Output power comparison for clean polycrystalline PV module and dirty Polycrystalline PV module

The power output of the PV module is much higher because of the high solar radiation in June and therefore these three months belong to the summer season so the power is high but when we look at the polycrystalline PV module the power is on less because of the dust, the dust deposition on its surface concludes that voltage become less when shadows enter the glass sheets of PV modules. It was found that the pure PV polycrystalline module showed higher output power than the polluted polycrystalline PV module and showed a higher percentage of reduction in output power due to dust accumulation on its surface.

3.2. Effect of Dust on the Efficiency of Polycrystalline PV Module

The module efficiency depending on the power output of the PV module and solar irradiance**.** And it degrades with the accumulation of dust on the surface of the PV module. Module efficiency is to be reversing about solar radiation and module temperature. At first, the module of the same type has almost the same module efficiency. But as the density of the dust increases on the surface of the PV module, the efficiency of the system becomes degraded after the analysis of each month. The solar park is located in the area where there are many large sand domes. In summer specially, due to environmental changes, the rapid blasts of air storms occur, which severely affect the performance of the PV system and reduce the efficiency of the operating system. In the recent study, the average efficiency for August for the

Polycrystalline PV module is 14.09% and for the dirty Polycrystalline PV module is 11.54%. There is 3% of average efficiency loss due to dust deposition. And similarly general to the three-month study the overall loss of efficiency is 3% showing a scary dust connection and efficiency in the PV module performance.

A similar impact was observed over the other two months of June and July. Reduced efficiency and its impact on the PV module are shown in Figures 8, 9 and 10 below.

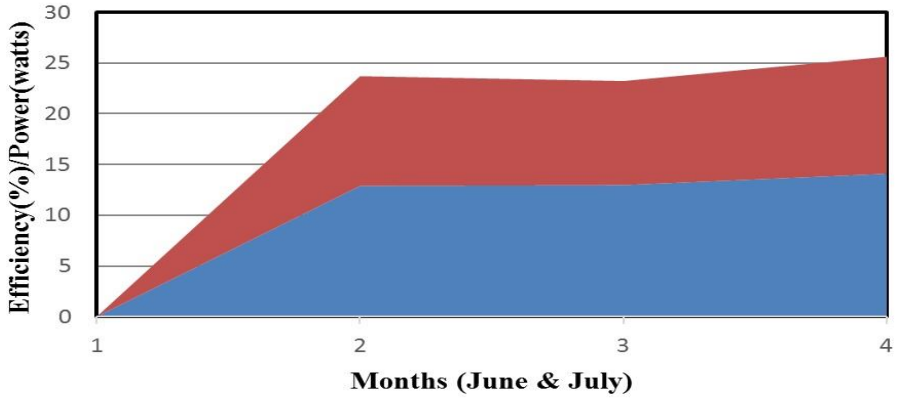

Figure 8. Variation of monthly average efficiency and Power for clean polycrystalline PV module

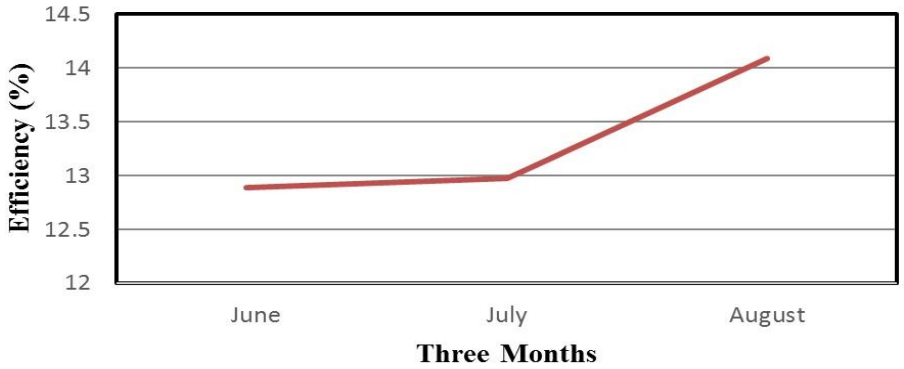

Figure 9. Variation of monthly average efficiency for dirty polycrystalline PV module

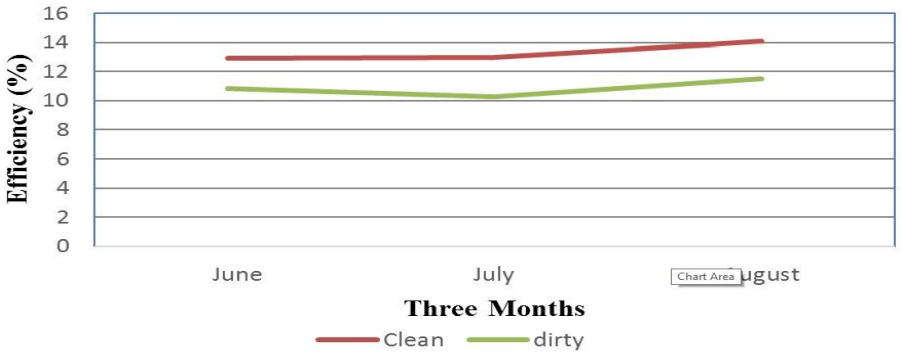

Figure 10. Efficiency comparison for clean and dirty polycrystalline PV modules

As shown in Figure 10, the percentage of efficiency reduced in the PV module has shown near the linear bond with the density of the dust Stored on the surface of the PV module. After time of 3 months, reduction of percentage of the efficiency of the p-Si PV module was 3.0% with a dust deposition of 0.6867 mg/cm2. During the study, weather conditions were normal, but most of the days were sunny with stormy sandstorms. In fact, there would not be a huge loss of module efficiency in this area. If solar panels would be exposed Pakistan's thicker dusty area, then it will reduce more power. Although rain causes module cleaning and increases output power, it cannot rely on it Cleaning like rain occurs occasionally and minimally in Bahawalpur. PV modules thus require regular Cleaning to minimize loss of efficiency.

4. Conclusion

In this research work, the performance of different PV modules of polycrystalline technologies was investigated thoroughly due to accumulation of dust on the surface of these modules. The PV modules of

this study were exposed to the outdoor operating conditions of Quaid-e-Azam Solar Park, Bahawalpur for three consecutive months of summer season (June, July and August). The results show that the performance of PV modules was decreased with the accumulation of dust deposited on their surfaces. The densities of dust accumulated on the surface of the PV module for June, July and August were 0.786 mg/ cm^2, 0.681 mg/cm^2 and 0.601 mg/cm^2 respectively at the end of that experiment. This study shows that the average output power was reduced up to 22% for June, 16% for July and 18% for August due to accumulation of dust on the surface of PV modules. There was also a significant decrease in efficiency of modules noticed during that study due to accumulation of dust. The percentage of reduction in efficiency of polycrystalline PV module was higher in the month of August as compared to June and July. Therefore, overall decrease in the average rate was 3% for polycrystalline PV- module after three months of environmental exposure. It is concluded that regular cleaning of PV module is required to minimize efficiency loss.

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