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SOLAR INSTALLATIONS AND THEIR APPLICATION

Experimental Investigation of Dust Accumulation on the Performance of the Photovoltaic Modules: a Case Study of Karachi, Pakistan

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Abstract—Karachi, Pakistan has great solar energy potential. Solar energy can be converted to electricity using photovoltaic (PV) technology. Dust accumulation can significantly suppress the performance of the PV modules. This research work is the first experimental study to examine the effect of dust deposition on the surface of PV modules in Karachi, Pakistan. An experimental setup of polycrystalline modules has been created by connecting three panels in a parallel arrangement. These panels were placed in an outdoor environment for one year to determine output power, efficiency and performance ratio. The results of this study indicated that the dust deposition on PV modules can cause an average reduction of 14.6 W/month in power, 0.3%/month in efficiency and 1.84% in performance ratio in the environment of Karachi. For PV modules of 780 W, the performance of PV modules is reduced by 2.21% due to dust deposition.

Keywords: dust accumulation, efficiency, performance ratio, photovoltaic, power output

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INTRODUCTION

The demand for electrical power is growing day by day all over the world [1, 2]. According to International Energy Agency (IEA), the energy requirement is anticipated to exceed 1 PW h (petawatt-hour) in 2021 [3]. The whole world needs to swing towards a cost-effective, sustainable and carbon-free renewable energy resource instead of fossil fuels [4–8]. And the most copious type of renewable energy is solar [9]. It can be easily utilized to meet electric power requirements using photovoltaics [10].

PV modules are frequently found in open locations like barren plains and dry regions [11]. In these scenarios, the adjacent areas are isolated and full of dirt. Therefore, PV modules are exposed to dust. Accordingly, it is critical to measure the dust's influence on the working characteristics of PV modules [12, 13]. Accumulation of dust on the PV module's surface is dependent on region and time [14].

Various researchers have studied the dust effect on PV modules in different regions. Kaldellis et al. [15] examined the impact of dust in Athens, Greece and found that the dust decreased the efficiency to 0.4%. Jiang et al. [16] carried out an experimental study on the effect of dust on the efficiency degradation of different modules. Adeniyi and Said [17] assessed the power output of PV modules, subjected to dust, in the eastern province of the Kingdom of Saudi Arabia. Rajput and Sudhakar [18] explored the effect of dust on the power and efficiency of PV modules in the central region of India. Cabanillas and Munguia [19] experimentally examined the behavior of efficiency of PV panels, deposited by dust, in the northwest of Mexico. Kumar et al. [20] studied the dust's effect on the conversion efficiency and maximum power point of PV modules in India. Mohamed and Hasan [21] investigated the influence of dust in the environment of Sahara. Sulaiman et al. [22] conducted an indoor study to evaluate the influence of artificial dust on the efficiency of PV modules. Bouchalkha [23] and Benatiallah et al. [24] also examined power degradation due to the dust effect on PV modules in Abu Dhabi and Sahara areas, respectively. The same has been experienced by Sadat et al. in Iran [25]. By critically reviewing the above studies, it is evident that there is no current experimental study which assesses the effect of dust deposition on PV modules in Karachi, Pakistan. Moreover, there is no consolidated study which evaluates the output power, efficiency and performance ratio in presence of dust.

The objective of this study is to observe the impact of dust on the power output, efficiency and performance ratio of PV modules. To achieve this goal, this original research article is organized as follows: Site description provides brief information about the site which is chosen for the experimental setup. The selected site is provided with the weather station which is used to measure the solar flux. Materials and methods discuss the PV modules used for this experimental study along with the procedure to record required data

Fig. 1. Weather station at NEDUET.

for the determination of power output, efficiency and performance ratio. Results and analysis presented the results and analysis of power output, efficiency and performance ratio before and after cleaning of modules, acquired from this experimental research.

SITE DESCRIPTION

Pakistan is one of the countries in the world which have an enormous potential of producing electrical energy using solar irradiation [26, 27]. This experimental study is conducted on the rooftop of the main campus of NED University of Engineering and Technology (NEDUET) Karachi, Pakistan (24°56′00.8″ N, 67°06′41.8″ E). The selected site is equipped with a weather station as shown in Fig. 1. This weather station is fitted with Kipp and Zonen CMP10 pyranometer for measuring global horizontal irradiance, a CSPS Twin-sensor Rotating Shadowband Irradiometer (RSI) for measuring diffuse horizontal irradiance, a CS215 temperature and relative humidity probe, CS100 barometric pressure sensor and a Campbell Scientific CR1000 data logger. This setup has a measurement uncertainty of less than 3% and is used to measure solar irradiance, used in our calculations.

Table 1. Specification of modules, used in experiment

Characteristic	Value
Manufacturer	Canadian Solar
Model	CS6P-260P
Rated power	260 W
Rated voltage	30.4 V
Rated current	8.56 A
Open-circuit voltage	37.5 V
Short-circuit current	9.12 A
Module efficiency STC	16.16%
Length	1.638 m
Width	0.983

MATERIALS AND METHODS

This experimental study is set out to explore the effect of duct accretion on PV modules. This study is conducted on the rooftop of NEDUET by using three polycrystalline modules, connected in a parallel arrangement. Each module has a rated power of 260 Wp with an efficiency of 16.16%. Therefore, the total rated power becomes 780 W. The specifications of installed modules are presented in Table 1. The modules are oriented to face south with an optimum fixed tilt angle of 24.9°. This study is conducted by recording initial readings from modules before cleaning. The readings are then again recorded after cleaning the modules with the help of a soft-bristled broom. For measuring the density of dust, a glass sheet is placed next to the experimental setup. The dust density is obtained by utilizing a digital weight balance to weigh the dust deposited on a glass sheet. The difference in weight before and after the deposition of dust on the glass sheet contributed information about the density of dust, accumulated on modules. The experimental setup before and after cleaning dust is shown in Figs. 2a, 2b, respectively. Solar irradiance of 1.000 W/m^2, cell temperature of 25°C and air mass ratio of 1.5 are considered as Standard Testing Conditions (STC) of PV module [28].

In order to conduct this research, data were recorded for all months of 2020 by considering their

Fig. 2. PV modules (a) before cleaning dust (b) after cleaning dust.

respective nth days [29]. The nth days are selected because the solar irradiance on nth day of a month is nearly equal to the average solar irradiance of that month. During the study period, modules remained at the rooftop's external environment. The readings were collected to acquire current and voltage values. The current (I) and voltage (V) of these modules were measured before cleaning and after cleaning and noted to simply find power (P) by using Eq. (1) [30]:

$$P = VI. \tag{1}$$

Percentage reduction in power can be found by using Eq. (2):

$$\%\ reduction\ in\ P = \frac{P_{clean} - P_{dirty}}{P_{clean}} \times 100\%. \tag{2}$$

The efficiency of modules can be calculated by using Eq. (3) [30]:

$$\eta = \frac{P}{SA} \times 100\%, \tag{3}$$

where S is the solar flux measured at the time of recording data. A is the total module area (m^2) and can simply be found by using Eq. (4):

$$A = length\ of\ module \times width\ of\ module \times number\ of\ modules. \tag{4}$$

Percentage reduction in efficiency can be found by using Eq. (5):

$$\%\ reduction\ in\ \eta = \frac{\eta_{clean} - \eta_{dirty}}{\eta_{clean}} \times 100\%. \tag{5}$$

Performance ratio (PR) is one of the best comparison metrics for our scenario. It can be determine using Eq. (6) [17]:

$$\text{PR} = \frac{P/P_R}{S/S_R}, \tag{6}$$

where P_R is the rated power of modules and S_R is the Solar Irradiance at STC.

The percentage reduction in performance ratio is determined using Eq. (7):

$$\text{PR} = \frac{\text{PR}_{clean} - \text{PR}_{dirty}}{\text{PR}_{clean}} \times 100\%. \tag{7}$$

RESULTS AND ANALYSIS

Dust accumulation has a significant influence on the performance of PV modules. The dust effect is influenced by a variety of climatic and environmental parameters. A sample of air carried dust was collected from the site and tested to find the composition of dust at the Soil Testing Laboratory of NEDUET. It was found that the provided sample contains 76% fine sand (diameter > 0.06 mm), 17% silt (diameter 0.06–0.002 mm), and 7% clay (diameter < 0.002 mm).

The data obtained from the weather station and experimental setup were recorded for the nth days of all months of 2020. The solar flux measured at the same time of recording data from the experimental setup is presented in Fig. 3. The actual parameters were used in this study to obtain power, efficiency and performance ratio, before and after cleaning. Percentage reductions for power, efficiency and performance ratio were also measured before and after cleaning.

The power outputs, before and after cleaning the modules, were computed for the nth days of 2020 and are presented in Fig. 4. It can be noticed that the power output of modules, before cleaning, varied from 611.44 to 648.70 W with a yearly average of 631.75 W. Also, the power output of modules, after cleaning, ranged from 632.64 to 666.00 W with a yearly average of 646.33 W. This corresponds to a significant average increase in power of 14.6 W/month after cleaning or we can say that the average power loss due to dust accumulation is 14.6 W/month. This power loss becomes greater as the thickness of dust increases. The density of dust, mea-

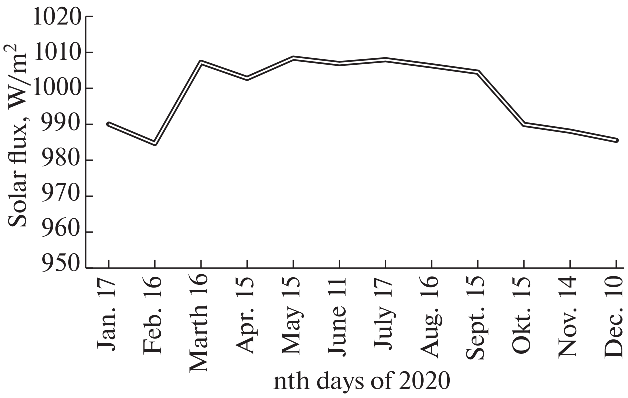

Fig. 3. Solar flux measured on nth days of 2020.

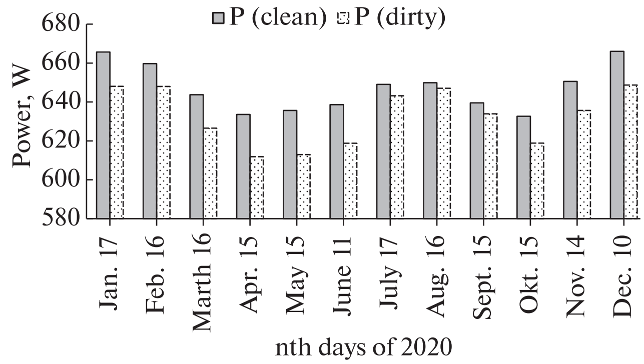

Fig. 4. Power outputs on nth days of 2020.

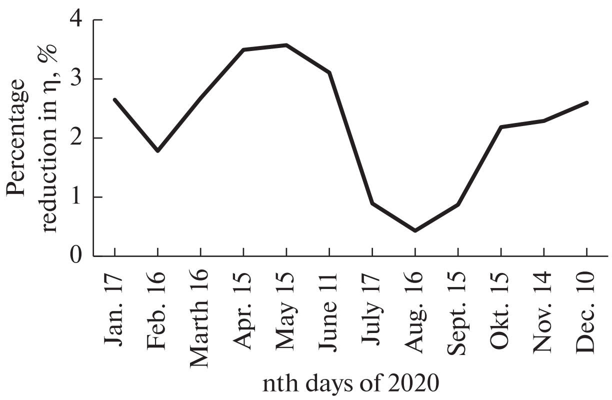

Fig. 5. Percentage reduction in output power.

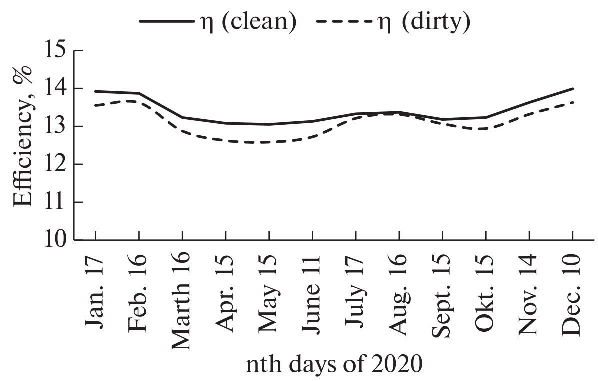

Fig. 6. Efficiencies on nth days of 2020.

sured at the instance of gathering data from modules, is presented in Table 2.

The percentage reduction in power was found by using Eq. (2) and presented in Fig. 5. It can be observed that the percentage reduction varied from 0.43 to 3.57% with a yearly average of 2.21%.

Table 2. Density of dust, measured on nth days of 2020

*n*th day	Density of dust, mg/cm^2
17-January	0.132
16-February	0.091
16-March	0.123
15-April	0.161
15-May	0.165
11-Jun	0.147
17-July	0.041
16-August	0.025
15-September	0.041
15-October	0.101
14-November	0.106
10-December	0.121

The efficiencies of PV modules before and after cleaning were determined using Eq. (3) and are presented in Fig. 6. It can be noticed that the efficiency of modules, before cleaning, ranged from 12.58 to 13.63% with a yearly average of 13.12%. Whereas, the efficiency of modules after cleaning varied from 13.05% in October to 13.99% in December with a yearly average of 13.42%. On an average basis, there is a difference of 0.3%.

The percentage reduction in efficiency was found by using Eq. (5) and presented in Fig. 7. It can be observed that the percentage reduction varied from 0.43 to 3.57% with a yearly average of 2.21%. It produces the same trend as of percentage reduction in power.

The performance ratios, before and after cleaning the modules, were determined for the nth days of 2020 using Eq. (6) and are presented in Fig. 8. It can be noticed that the value for performance ratio of modules, before cleaning, varied from 77.93 to 84.93% with a yearly average of 81.26%. Also, the performance ratio of modules, after cleaning, ranged from 80.82 to

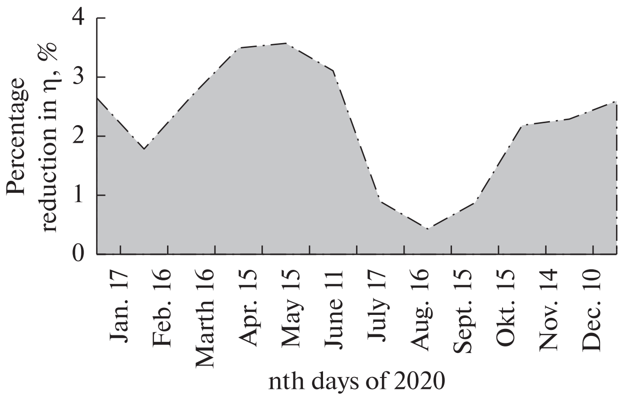

Fig. 7. Percentage reduction in efficiency.

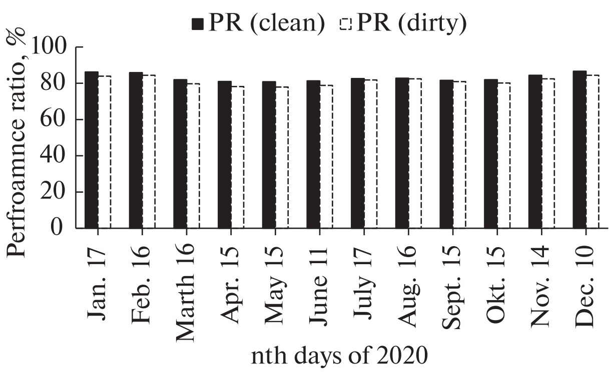

Fig. 8. Performance ratio for nth days of 2020.

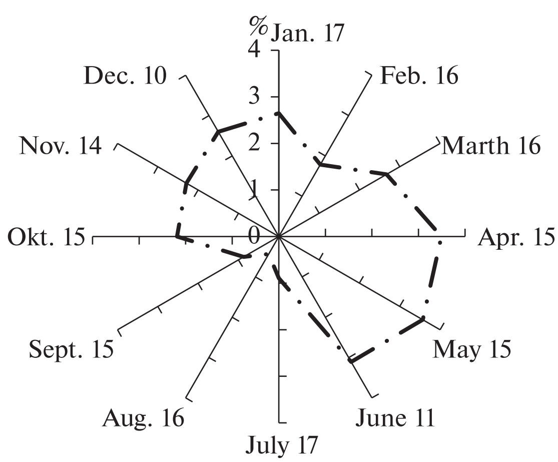

Fig. 9. Radar map of percentage reduction in performance ratio.

86.64% with a yearly average of 83.09%. This corresponds to a substantial increase in the annual average performance ratio of 1.84%.

The percentage reduction in performance ratio was found using Eq. (7). The radar map of percentage reduction in performance ratio is presented in Fig. 9. It can be observed that the percentage reduction of performance ratio varied from 0.43 to 3.57% with a yearly average of 2.21%. It produces the same trend as of percentage reduction in power and efficiency.

Therefore, it can be extracted that the values of power output, efficiency and performance ratio were significantly reduced in months with light or no rainfalls (e.g. March, April, May, June) while the percentage reductions of power output, efficiency and performance ratio were minimal in the months of moderate to light rain (e.g. July, August, September). The main difference in the environment of PV modules, between raining and non-raining days, is the presence of dust. Dust can impactfully reduce the performance of PV modules. More the thicker the dust layer, the more will be the power loss.

CONCLUSIONS

PV is one of the most dependable renewable energy technologies which are playing its part in slashing the electricity demand and all over the world. Therefore, it will be a great benefit if the losses occurred in PV will be reduced to as much as possible. This research is focused to investigate the effect of the accumulation of dust on the power efficiency and performance ratio of PV modules, experimentally. It was noticed that the average yearly values of power before and after cleaning were found to be 631.75 and 646.33 W, respectively. The dust deposition on the surface of modules can cause a significant reduction in power of around 14.6 W/month. The average annual values of efficiency, before and after cleaning were found to be 13.12 and 13.42%, respectively. The presence of dust on the modules can cause a decrement in the efficiency of around 0.30%/month. The average annual values of performance ratio, before and after cleaning, were computed to be 81.26 and 83.09%. This corresponds to a substantial increase in the monthly average performance ratio of 1.84% after cleaning. Moreover, by determining the percentage reduction in power, efficiency and performance ratio, it was found that the annual average percentage increment of power, efficiency and performance ratio can be increased to 2.21% after cleaning of PV modules. From this study, it can be extracted that for a 780 W system the performance of the PV modules is reduced by 2.21% due to dust deposition. This performance can be significantly increased by cleaning modules at short and regular intervals. For a much larger system, this effect can be further amplified.

Studies can also be conducted to check the feasibility of the arrangement of a dedicated cleaning person or a protective coating or na cleaning system for dust.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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