Journal of Renewable Energy and Sustainable Development (RESD) Volume 9, Issue 1, June 2023 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2023.09.1.001

Received on, 09 January 2023 Accepted on, 06 February 2023 Published on, 16 February 2023

Non-Uniform Dust Distribution Effect On Photovoltaic Panel Performance

Saman S. Jaafar[1a], Hiwa A. Maarof[1b], Renas T. Salh [1c], Hoshang Sahib[1d], Yousif H. Azeez[1e]

[1]Physics department, College of Science, University of Halabja, Halabja, KRG-Iraq

[a]saman.jaafar@uoh.edu.iq, [b]Hiwa.Maroof@uoh.edu.iq, [c] renas.salh@uoh.edu.iq, [d]hoshang.sahib@uoh.edu.iq
[e]yousif.husain@uoh.ed.iq

ABSTRACT

A novel experimental method for power efficiency loss is presented in this paper. It is used to quantitatively determine the impact of dust deposition on the PV power generation panel. To determine the selection range of unknown parameters in the experiment process, a photovoltaic panel with five collected dust samples (Toner (C), Soil, Cement (CaO, SiO4), Gypsum (Ca2SO4.2H2O), and Sand (AL2O3, SiO4)) is designed. According to experimental results, the extinction coefficient for the five pollutants are recorded. Eventually, the impact of dusts on the results is proved by repeating in two continuous days of same conditions. The results show that the proposed process has a high effect on the reduction of output power (62% to 96%), decrease of irradiance (34% to 93%) and increase of output power due to increase of tilt angle as a doubling of power except toner. The experimental and calculated results are in agreement. The results show that non-uniform distribution of dust deposit pollutants on the photovoltaic panel significantly reduces the power output.

Index-words: *Dust deposition, Dust accumulation, Power reduction, Solar PV performance, Extinction coefficient.*

I. INTRODUCTION

With the industrial revolution and the increase in energy consumption, concerns about the environment and global warming have been raised (Mahmood, Jaafar, and Mustafa 2022). Recent worldwide efforts to improve energy security and reduce climate change have necessitated a fundamental shift in the way solar energy is handled [2]. Since photovoltaic (PV) phenomena were studied and solar cells were being made, countries have been using and relying on solar panels and modules for their electrical energy needs. The two prominent problems of PV are concerned with the environmental issues and energy that restricts the continuous development of economy and society. Installation of the solar panel depends on sseveral uncontrollable factors, and dust deposition on the surface of the PV is an important reason to decrease the power. Dust accumulation on the PV can scatter, reflect, and absorb the light, that will seriously drop the transmission of light and reduce the power (Fan et al. 2021). Furthermore, the variety of environmental factors decreased the efficiency of the PV by more than 30% (Memiche et al. 2020). The chemical decomposition, density, and size of dust particles are the reason behind decreasing the power (Mostefaoui et al. 2018) (Said et al. 2018). The design of dust cleaning on the surface of solar cells is highly recommended to increase the PV output power (Parrott et al. 2018). Dust accumulation of (10 g/m^2) decreases the performance of the PV by 34% (Chen et al. 2019), based on Salimi et al. (2020). The adhesion of dust particles is proportionally related to the reduction of the output power of PV (Kawamoto and Guo 2018). There are growing appeals for cleaning steps that are more useful to raise the performance of a dusty panel (Lorenz et al. 2019). Also, the industrial activities lead to deposit of different kinds of dust particles on the PV, which drops the electrical efficiency from 29% to 64% based on the types of deposited dust (Andrea, Pogrebnaya, and Kichonge 2019). The deposition of dust on the PV's surface will increase directly with the density and the size of particles, but it changes inversely with the diaphaneity of the particles (Xingcai and Kun 2018). Recently, theoretical developments have revealed that dust accumulation drops the PV's power by 29, 31, and 50% (Benghanem et al. 2018; Mostefaoui et al. 2018; Mussard and Amara 2018). Jaszczur (2018) stated that efficiency is reduced by 2.1% when 300mg of dust particles are deposited on each square meter. PV power is reduced directly with particles' densities; meanwhile, it has been changed based on the tilt angle of the PV. The tilt angle of 0° to 45° reduces performance by 37.6% to 10.9%, respectively (Hachicha, Al-sawafta, and Said 2019).

A suggested way to weaken the adhesion of dust on the glass surface of the PV is to use hydrophobic coating when, for tilt angles of 30° and 60°, the power reduction is 44.4% and 11.2%, respectively (Zhang et al. 2019). During dust storms, for angles of 0° to 45° tilt angle, the power efficiency of PV drops from 58.2% to 20.7% (Khodakaram-Tafti and Yaghoubi 2020) (Hachicha et al. 2019). The dirty solar panel has power production of 10% lower than the clean one. The different dust samples have been tested and it was revealed that they have reduced the performance of the PV from 5% to 30% (Chaichan and Kazem 2020). The main adhesion forces between the dust particles and the PV surface are studied such as:

Capillary, Van der Waal, electrostatic and gravitational forces (Isaifan et al. 2019). Wang et al. (2018) showed that the coated PV with Fluorine super-hydrophobic film has less effect than the silicon super-hydrophobic film. The rainy weather can be mentioned as an excellent natural cleaner of dust on the PV (Panels 2020) (Al-Housani and Bicer 2019). A common strategy used to study the influence of dust deposition on the solar panel surface is to take a period of sandstorm going to deposit more thickness of dust particles and it leads to reducing the transmission of light (Mostefaoui et al. 2018). For decades, one of the most popular ideas for maintaining the highest performance in PV is the idea that the accumulated dust must be removed from its surface. The most detailed review of research has been done from 2012-2015, which shows the effects of dust accumulation on the PV in detail during the study of Costa, Diniz, and Kazmerski (2018). In Saudi Arabia, to remove the PV from deposited dust, they used jet water with low pressure, and the performance of the solar cell farm increased by 27% (Systems 2019). While the weak dust of density 0.644 g/m^2 reduced the performance of the PV by 7.4% (Chen et al. 2020). Various research on dust accumulation show results on how the different types of deposited dust particles will cause the decrease of the efficiency of the solar cells (Aljuhani et al. 2021; Alnasser et al. 2020; Chanchangi et al. 2020a, 2020b; Dhaouadi et al. 2021; Dida et al. 2020; Drame et al. 2021; Fan et al. 2021; Ilse et al. 2023; Javed et al. 2021; Kazem et al. 2020; Laarabi et al. 2021; Liu et al. 2021; Mustafa et al. 2020; Ullah et al. 2020; Zhang 2020). The rising temperature due to the high amount of solar radiation intensity caused a decrease in the PV cell's efficiency (Kazem and Chaichan 2019). The layering of the dust particles is mostly related to the temperature of the PV (Jaszczur 2019).

The PV of higher surface temperatures has lower accumulated dust (Gupta et al. 2019). The dust deposition on the PV's surface caused an increase in its surface temperature based on the study of Chaichan and Kazem (2020).

Cleaning the different panels is shown by the temperature-correction performance ratio (Guo et al. 2019). On the other hand, the cleaning process enhances the efficiency by 32.7% in a 1MWp PV farm (Hammoud et al. 2019). Based on the studies, the PV dust accumulation caused the thermal property settlement neither the electrical nor the optical (Gupta et al. 2019).

Finally, concentrating on complexity of dust distribution density and reduction power of PV panels, the researchers designed an experimental set up and measured the (I-V) and (P-V) data to evaluate the degree of dust accumulation on PV that exists in the environment. Firstly, the different types of dust samples are collected and each one is distributed on PV surface, the regular power production of PV panels is analysed, the basic equations form of dust density and power reduction rate is given, and dust density with irradiance is appointed. Basically, the analysis of the obtained behaviour of each of the five sample pollutants, containing distribution, concentration, composition, and the effect of dust particles on light transmission under different mass density and tilt angle is carried out. To ensure the reliability of the experimental results, some principle equations are used to to show the wrong analysis method for dust concentration.

The five-dust samples and their chemical decomposition are Toner (C) (Parthasarathy 2021), Cement (CaO, SiO_4) (Oliveira and Moreira 1989), Sand (AL_2O_3, SiO_4) (Ibbeken and Schleyer 1991), Soil, and Gypsum ($Ca_2SO_4.2H_2O_2$) (Bolukbasi, Kurt, and Palacio 2016). The basic contributions can be explored as follows:

- Different curve behaviour of dust particles and the reduction of power production at the same irradiance for obtaining the effect quantity of dust deposition are plotted.
- To guarantee the experimental process results, different scenarios are applied like irradiance reduction with respect to the dust distributed density, and influencing the coefficient of tilt angle for each of the five collected dust samples.
- The experimental and calculated results are in agreement.

TABLE I: NOMENCLATURE

Symbols	Meaning
PV	Photovoltaic
C	Carbon (Chemical decomposition of printer toner)
CaO, SiO_4	(Chemical decomposition of Cement)
AL_2O_3, SiO_4	(Chemical decomposition of Sand)
Ca_2SO_4	(Chemical decomposition of Gypsum)
R_{sh}	Shunt resistance of solar cell
Rs	Series resistance of solar cell
I_d	Diode current
Φ	Irradiance
$I_{\Phi 2}$	Light intensity current of clean PV
$I_{\Phi 3}$	Light intensity current of dusty PV
K	Boltzmann's constant
Si	Chemical abbreviation symbol of Silicon atom
Ge	Chemical abbreviation symbol of Germanium atom
T	Temperature
σ_{ext}	Extinction cross-sections coefficient
σ_{scat}	Scattering cross-sections coefficient
σ_{abs}	absorption cross-sections coefficient
b_{ext}	Extinction coefficient
b_{scat}	Scattering coefficient
b_{abs}	Absorption coefficient
ρ	Mass density (g/cm^2)
Φ_1	Irradiance intensity of sun
Φ_2	Irradiance intensity value after passing through plane glass
Φ_3	Irradiance intensity value after passing through plane glass and dusty glass
m	Mass of Sample dust
I	Current
A	Area (m^2)
η	Efficiency of PV
IR	Infrared radiation
$P_{max(dustyGlass)}$	Maximum power of dusty glass
$P_{max(clearGlass)}$	Maximum power of clear glass
x	Distance
W	Power Unit (Watt)
I	Current
V	Voltage

http://dx.doi.org/10.21622/RESD.2023.09.1.001

II. METHODOLOGY

A. Position of the Problem

As a basic reason that influences the output voltage (V) and output current (I) of PV, dust deposit on the solar panel can reduce the output power (I.V). The PV panel of internal circuit like Figure 1 is shown and the main parameters of V and I which affect the solar cell's actual power are described.

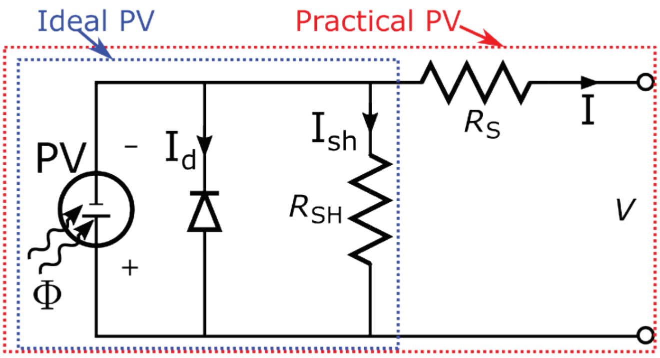

Fig.1. Solar Cell Internal Circuit

$$I_{\Phi_3} = I_{\phi 2} - I_0\left\{e^{\left[\frac{q(V+I_L R_S)}{n\times k\times T}\right]} - 1\right\} - \frac{V+I_L R_S}{R_{sh}} \qquad (1)$$

Where I_{Φ_3}, $I_{\Phi 2}$ are light current, I_0 = saturate Current of diode, R_s is series resistor, K Boltzmann constant, T is temperature, n is constant (Kazem et al. 2022).

The influence of dust accumulation on reducing PV output power can affect the efficiency (η) and it can be described as:

$$\eta = \frac{P_{max}}{Pin} \times 100\% \qquad (2)$$

Where P_{max} is output power of PV cell that is usually determined by measuring the output voltage V and output current I. P_{in} is input power of light to the PV which is (irradiance × Area of PV) (Ali et al. 2021).

B. Study Area

Continuously, the experimental process is done in the Halabja city-Kurdistan region of Iraq, as shown on 1st and 2nd October 2022. This city has an altitude angle and the azimuth angles are 35° and 5° (Jaafar and Maarof 2022).

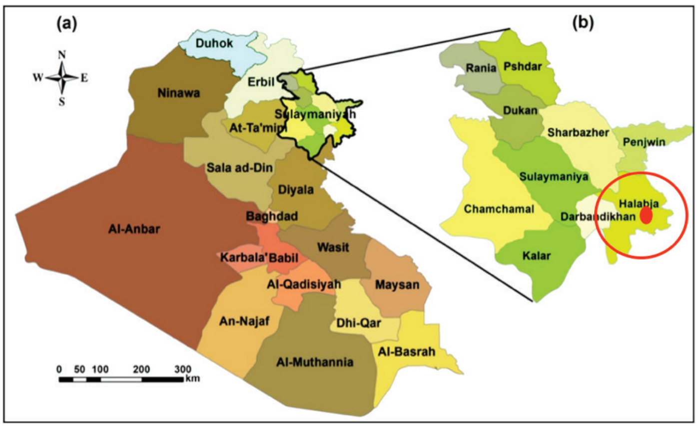

Fig.2. Location of Halabja City on Map (a) Iraq Map (B) Halabja and Sulaymaniyah Provinces (Halabja City (Zakaria et al. 2013)

Naturally, this location and in general most of the Iraqi provinces are under influence of dusty air in some months of year because of the existence of desert land in Iraq and other neighbouring countries. More than this, due to industrial actives, the same types of the collected dust pollutant exist in the environment air. For that reason, these kinds of the pollutants are collected and experimentally analysed to determine their effect on decreasing the PV performance.

Now, to have more accurate analysis data on dust accumulation on surface of PV, the calculation of the output power is usually done for the case of dusty surface (P_{dusty}) and clean surface (P_{clean}). After that the researchers defined the power reduction rate, which is used to present the best achieved efficiency (Ullah et al. 2020). Thus

$$L(t) = \frac{P_{clean} - P_{dusty}}{P_{clean}} \times 100\% \qquad (3)$$

Where b_{ext} is the extinction factor due to the dust particles, the P_{dusty} is the output power of dusty panel and P_{clean} is output power of clean PV panel.

For having more detail and raising the level of accuracy the b_{ext} can be calculated as dependent on and represent as:

$$\Phi_3 = \Phi_2 e^{-(b_{ext} \cdot x \cdot \rho)} \qquad (4)$$

Remark: For increasing the level of accuracy and test the next pollutants the previous one was totally removed from the surface of the PV. When the extinction coefficient of used plane glass b_{ext} 0.028, it can be easy to measure the reduced irradiance for each dust samples with different mass density.

The extinction coefficient can be determined from both scattered and absorption coefficient as (Redmond,Dial,and Thompson 2010):

$$b_{ext} = b_{scat} + b_{abs} \qquad (5)$$

Where b_{scat}, b_{abs} is scattered and absorption coefficient, respectively.

Due to absorption) coefficient of dust particle the intensity of light reduced, then Lambert's Law stated as:

$$\Phi_3 = \Phi_2 e^{-(\mu x)} \qquad (6)$$

Where is the intensity reduced due to (dusty PV), initial intensity of light after pass through clean PV and x is the interaction distance between the light and the dust particles.

C. Experimental Setup

After establishing the basic theory of experimental process, five prepared dust particles on PV panels in different amount of masses are investigated. Mainly, to detect the exact effectiveness coefficient b_{ext} and the reduced actual power, a real design of experiment is designed.

Volume 9, Issue 1, June 2023 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2023.09.1.001

D. Experimental Process

Dust accumulation on PV cell in the real environment, a single PV panel of 15W power generation for experiment setup is set up. The dust samples and experiment set up are given in Figures 3 and 4.

In the first part, a plane glass is used to put on the PV surface. The aim of that was just for measuring the irradiance after going through the plane glass and the accumulated dust on plane glass. After that an outdoor PV power generation system is established. Three radiation levels are measured during the experiment, and the sun radiation range was from 925 to 1000 W/m^2 and this rang was between 560 to 700 W/m^2 for plane glass. In the second part, an electronic balance is used to calculate the dust mass density of the plane glass sheet. Here, it was necessary to control the mass of deposited pollutants in the third part, so that dust density range is 0.2840 g/cm^2 to 1.4198 g/cm^2. In the third part, the dust distributing process is done manually. Regarding to the non-uniform distribution of dust, it will have the same effect on the PV power same as the natural uniform deposition. After determining dust density and output power from the plotted curves, the effect model of dust accumulation and power efficiency is analyzed and obtained and the validity of the experiment is proved by the actual conditions.

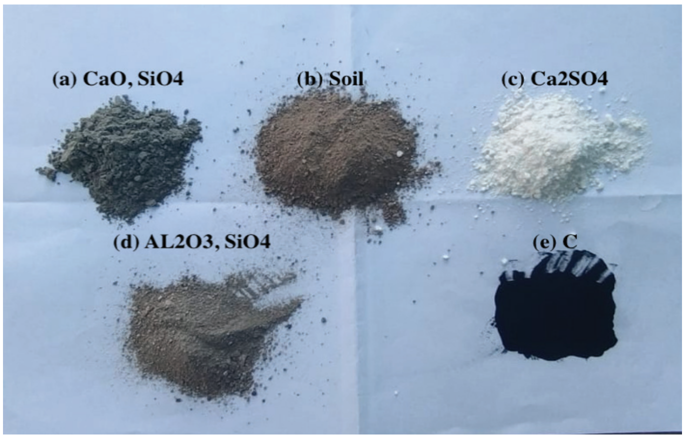

Fig.3. Different Samples of Dust Particles (a) CaO, SiO4 (b) Soil (c) Ca_2SO_4 (d) AL_2O_3, SiO_4 (e) C

Each type of dust pollutants is subjected to two of its chemical decomposition. Different dust masses are used for each sample, resulting in five levels of each sample. The density of each deposited dust is in a specific range. When the density is low, it has less influence on the power of PV panels. To keep going forward with the output power reduction, more dust pollutants are tested. The researchers appropriately increased the density of deposited dust sample. The accumulation steps are as follows:

Step 1. Measure the light irradiance directly from the sun, then measure it again after going through plane glass and finally for the third time after depositing the dust on the glass surface the irradiance is measured behind dusty plane glass.

Step 2. Lie the PV panel face up and put the plane glass on it and an area is specified by a marker in order not to deposit the dust out of PV panel area in case of high accuracy of dust influence on panel efficiency.

Step 3. By using voltmeter, ammeter, and a rheostat all V-I data are measured and the power is obtained for each couple I and V data. P-V curves are plotted as can be seen in Fig. 6.

Step 4. For all type of dusts with specific mass density different tilt angle 0° to 45° and for C case extra angle of 60° are tested. Step 3 is repeated for all tilt angle and the data are plotted.

To reduce the error factor of the experiments process, the steps are repeated on two continuous days in same natural conditions.

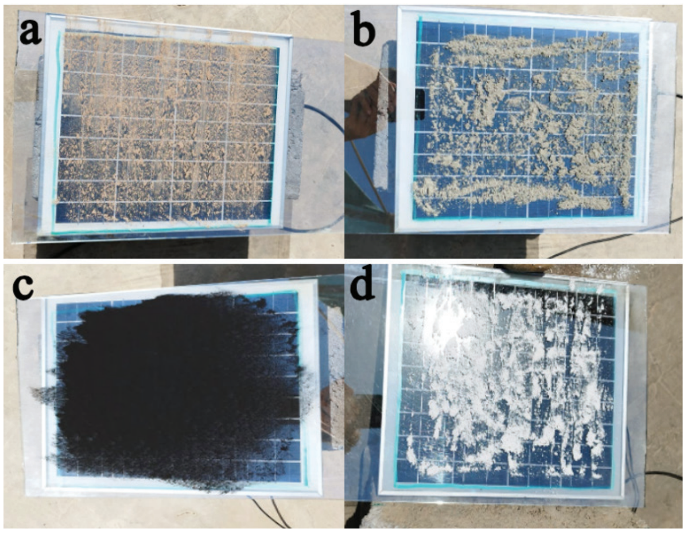

Fig.4. a: Soil and b: CaO,SiO2 c: C, d: $Ca_2SO_42H_2O_2$ Deposited of PV Surface

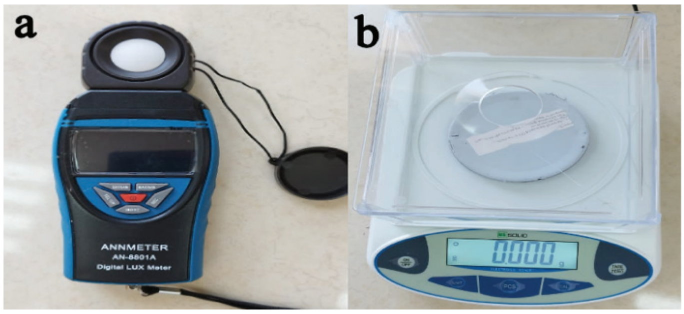

Fig.5. a: Digital Lux Meter, b: Electronics Balance Device

III. RESULTS AND DISCUSSION

In this part, the experimental outcome will be analyzed in detail. In subsection 5.1, the all parameters characteristics such as V-I curve, V-P curve, , , and different tilt angle of five dust pollutants are investigated.

A. Analysis Impact of Dust Deposition on PV Panels

In order to acquire the power reduction factor, the experiment is set up to test and measure the energy performance of the PV panel, including output voltage, current, power, irradiance and tilt angle. Fig. 6 shows the power output curves for all dust pollutants under unchanged radiation with a dust density of five levels. In addition, each sub-Figure shows the evolution of the power efficiency of the same dust pollutant of different

 Volume 9, Issue 1, June 2023 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2023.09.1.001

mass (five concentrations of pollutant accumulation). Experimental results show that the output power of the PV panels decreases in different degrees with the increase of mass density of each accumulation effect.

At low density, the coverage area of toner on PV is more, which has high effect on power output. When the concentration of toner reaches 0.775 g/cm^2, the output power drops to zero. When the soil concentration raised to the same value, the output power changes to 2.4 W and it is significantly lower than the power of clean PV. The output power is 2.86 W, when the maximum density is 1.4119 g/cm^2 for Al_2O_3, SiO_4. CaO, SiO_4 is one of the pollutants that have reduce the output power to 2.17 W of the same density as Al_2O_3, SiO_4. It can be sensed that the output power of PV panels is highly sensitive to toner pollutant because of the its colour and adhesion.

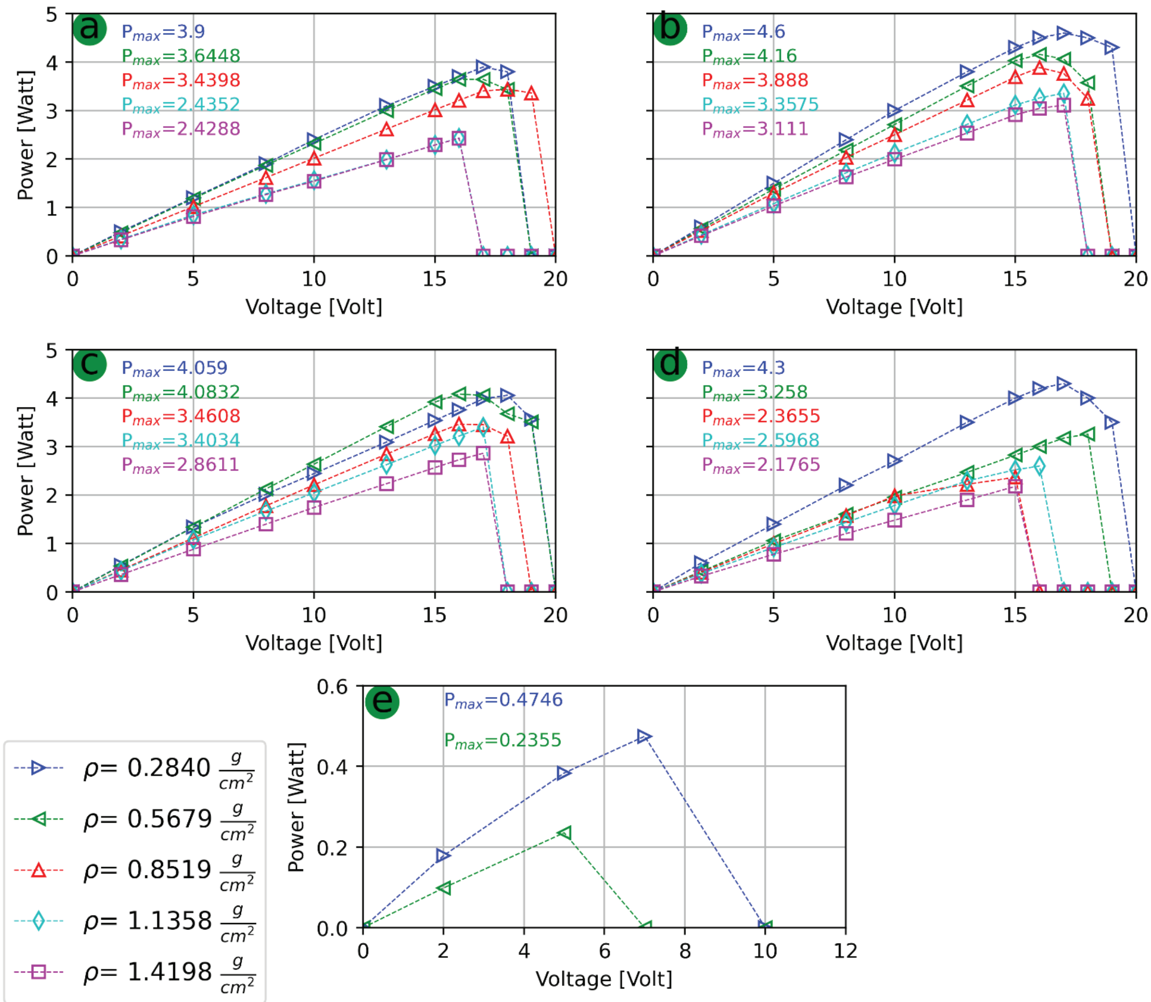

Fig.6. V-P Curves Characterization a: Soil, b: $Ca_2SO_4.2H_2O$, c:,AL_2O_3, SiO_2 d: CaO,SiO_2,

e: C.

From Fig. 7, the **plot (a):** represents five different curves of the same mass density. When the density is 0.5679 g/cm^2, the power decline trend is 62.35%, 66.95%, 69.05%, 63.35% and 96.65% for soil, (Al_2O_3, SiO_4), (CaO, SiO_4), ($Ca_2SO_4.2H_2O$) and (C), respectively. **Plot (b):** among all pollutants, soil, ($Ca_2SO_4.2H_2O$) and (Al_2O_3, SiO_4) rapidly changed with increasing the concentration. However, for (CaO, SiO_4), the output power extremely decreased from 0.28 g/cm^2 to 0.56 g/cm^2 and after that the change went slowly. For toner, output power rapidly goes to zero by concentration of 0.56 g/cm^2. **Plot (c):** soil, (Al_2O_3, SiO_4) and (CaO, SiO_4) by increasing the tilt angle, the effectiveness of their concentration will be reduced because the output power of each of the three increased. The output power increased highly after angle of 30° due to low adhesion. Toner C has a small particle size and high adhesion, and the output power goes forward constantly. **Plot (d):** toner pollutant highly reduced the irradiance, but other types of dust uniformly decreased the irradiance. The low concentration of pollutants has a little effect on irradiance, while high concentration of each influenced the irradiance significantly.

Volume 9, Issue 1, June 2023 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2023.09.1.001

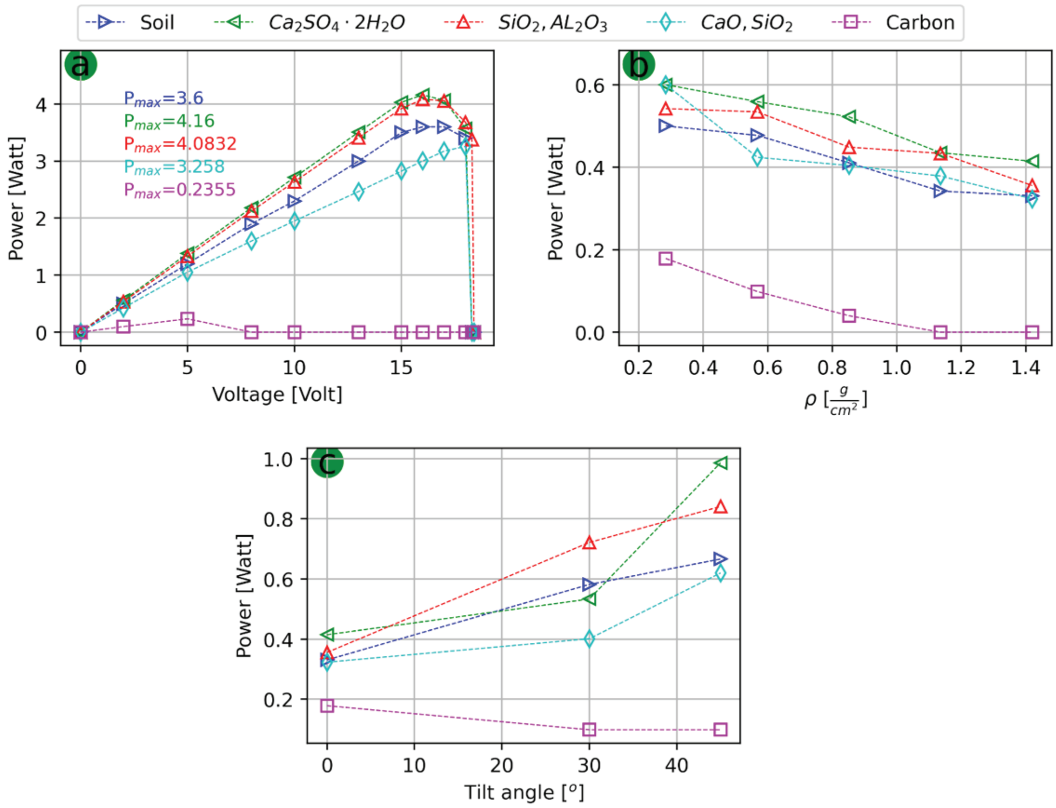

Fig.7. Curves of All Pollutants a: P - V curves, b: P – ρ curves c: P – tilt angle curve

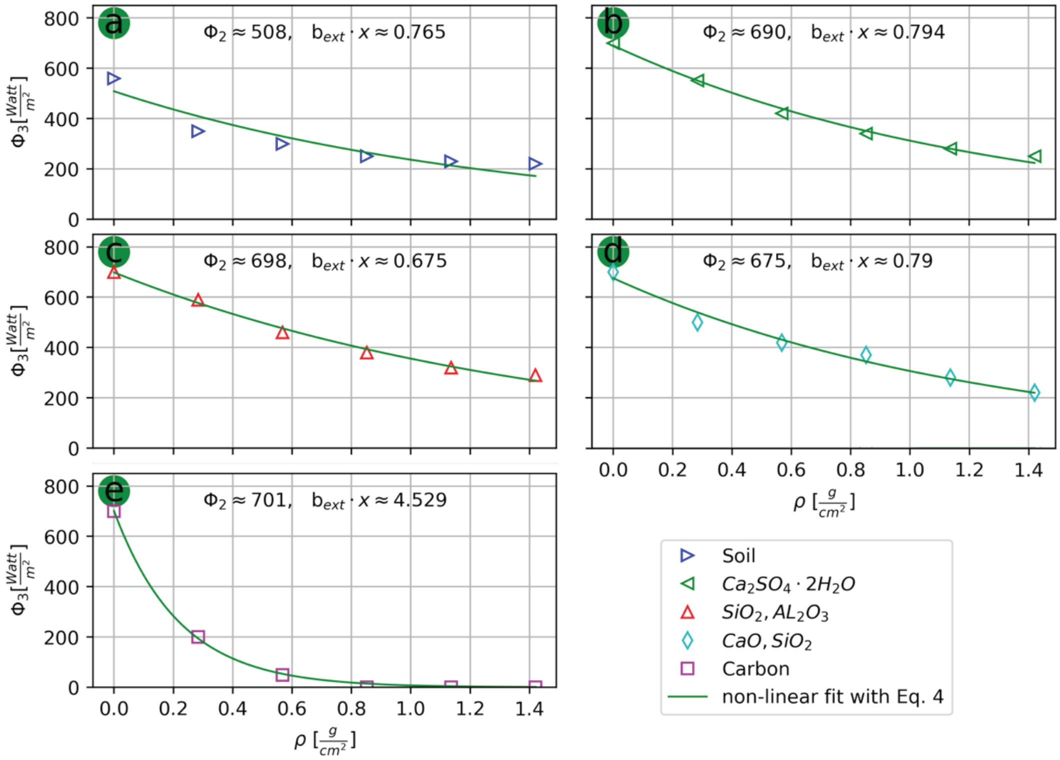

Fig.8. Φ_3 –ρ Curves with their Fitting Curves to Find the Value of bext .x

IV. CONCLUSIONS

The impact of five collected dust pollutants (Toner (C), Soil, Cement (CaO, SiO_4), Gypsum ($Ca_2SO_4.2H_2O$), and Sand (AL_2O_3, SiO_4) on the actual power of PV panels are determined in this study. Fortunately, the effectiveness of extinction coefficient of various dust particles for different dust decomposition on the power of PV panels with various concertation is determined. The overall the results could be as:

1. Dust deposition has a remarkable inhibitory influence on PV panels output power, and its efficiency debilitation depends on the kind of pollutant colour, composition, and more on the density of dusts.

2. Joining the impact of concentration on the irradiance ratio of PV panels output power experimentally established.

3. The outcomes present that the calculated output power reduced (62% to 96%), irradiance (34% to 93%) decreased and increasing of output power due to increasing of tilt angle as redouble the power, But toner double down the power.

4. The extinction coefficient of all pollutants has been found and the toner has the highest extinction with (AL_2O_3, SiO_4).

Although the influence of different dusts is collected, their accumulation on the PV is considerably not uniformly, and there may be difference extinction coefficient various points on PV panel. In the future, the used model of uniform distribution condition of pollutant should be further developed to have a uniform experimental process for the recording of V-I and V-P graphs of pollutants.

Contribution

Saman Jaafar carried out system building, data analysis, and interpretation experiments. Hiwa Abdlla Maarof and Renas T Salh cooperated as a partner in data analysis. Hoshang Sahib did the plots and fitting of the data measures. Yousif Azeez cooperated as paraphrasing and rewrite the draft version. All authors have read and agreed to the published version of the manuscript.

Declarations

Ethical approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Conflicts of interest: The authors declare no conflict of interest

References

[1] M. Al-Housani, Y. Bicer, and M. Koç, “Assessment of various dry photovoltaic cleaning techniques and frequencies on the power output of CdTe-type modules in dusty environments,” Sustainability (Switzerland), vol. 11, no. 10, 2019, doi: 10.3390/su11102850.

[2] S. Ali Sadat, J. Faraji, M. Nazififard, and A. Ketabi, “The experimental analysis of dust deposition effect on solar photovoltaic panels in Iran’s desert environment,” Sustainable Energy Technologies and Assessments, vol. 47, 2021, doi: 10.1016/j.seta.2021.101542.

[3] M. Aljuhani, M. R. Gomaa, T. S. Mandourah, and M. A. Mowffaq, “The Environmental Effects on the Photovoltaic Panel Power : Jeddah Case Study,” vol. 44, no. 6, pp. 251–262, 2021.

[4] T. M. A. Alnasser, A. M. J. Mahdy, K. I. Abass, M. T. Chaichan, and H. A. Kazem, “Impact of dust ingredient on photovoltaic performance: An experimental study,” Solar Energy, vol. 195, 2020, doi: 10.1016/j.solener.2019.12.008.

[5] Y. Andrea, T. Pogrebnaya, and B. Kichonge, “Effect of Industrial Dust Deposition on Photovoltaic Module Performance: Experimental Measurements in the Tropical Region,” International Journal of Photoenergy, vol. 2019, 2019, doi: 10.1155/2019/1892148.

[6] M. Benghanem, A. Almohammedi, M. Taukeer Khan, and A. A. Al-Mashraqi, “Effect of dust accumulation on the performance of photovoltaic panels in desert countries: A case study for Madinah, Saudi Arabia,” International Journal of Power Electronics and Drive Systems, vol. 9, no. 3, 2018, doi: 10.11591/ijpeds.v9.i3.pp1356-1366.

[7] A. Bolukbasi, L. Kurt, and S. Palacio, “Unravelling the mechanisms for plant survival on gypsum soils: An analysis of the chemical composition of gypsum plants from Turkey,” Plant Biol, vol. 18, no. 2, 2016, doi: 10.1111/plb.12401.

[8] M. T. Chaichan and H. A. Kazem, “Environmental Effects Experimental evaluation of dust composition impact on photovoltaic performance in Iraq,” Energy Sources, Part A Recover. Util. Environ. Eff., vol. 00, no. 00, pp. 1–22, 2020, doi: 10.1080/15567036.2020.1746444.

[9] Y. N. Chanchangi, A. Ghosh, S. Sundaram, and T. K. Mallick, “An analytical indoor experimental study on the effect of soiling on PV, focusing on dust properties and PV surface material,” Solar Energy, vol. 203, 2020, doi: 10.1016/j.solener.2020.03.089.

[10] Y. N. Chanchangi, A. Ghosh, S. Sundaram, and T. K. Mallick, “Dust and PV Performance in Nigeria: A review,” Renewable and Sustainable Energy Reviews, vol. 121. 2020. doi: 10.1016/j.

rser.2020.109704.

[11] J. Chen, G. Pan, J. Ouyang, J. Ma, L. Fu, and L. Zhang, "Study on impacts of dust accumulation and rainfall on PV power reduction in East China," Energy, vol. 194, 2020, doi: 10.1016/j.energy.2020.116915.

[12] Y. Chen et al., "Experimental study on the effect of dust deposition on photovoltaic panels," in Energy Procedia, 2019, vol. 158. doi: 10.1016/j.egypro.2019.01.139.

[13] S. C. S. Costa, A. S. A. C. Diniz, and L. L. Kazmerski, "Solar energy dust and soiling R&D progress: Literature review update for 2016," Renewable and Sustainable Energy Reviews, vol. 82. 2018. doi: 10.1016/j.rser.2017.09.015.

[14] R. Dhaouadi, A. Al-Othman, A. A. Aidan, M. Tawalbeh, and R. Zannerni, "A characterization study for the properties of dust particles collected on photovoltaic (PV) panels in Sharjah, United Arab Emirates," Renew Energy, vol. 171, 2021, doi: 10.1016/j.renene.2021.02.083.

[15] M. Dida, S. Boughali, D. Bechki, and H. Bouguettaia, "Output power loss of crystalline silicon photovoltaic modules due to dust accumulation in Saharan environment," Renewable and Sustainable Energy Reviews, vol. 124, 2020, doi: 10.1016/j.rser.2020.109787.

[16] M. S. Drame, D. Diop, K. Talla, M. Diallo, B. D. Ngom, and B. Nebon, "Structural and physicochemical properties of dust collected on PV panels surfaces and their potential influence on these solar modules efficiency in Dakar, Senegal, West Africa," Sci Afr, vol. 12, 2021, doi: 10.1016/j.sciaf.2021.e00810.

[17] S. Fan, Y. Wang, S. Cao, T. Sun, and P. Liu, "A novel method for analyzing the effect of dust accumulation on energy efficiency loss in photovoltaic (PV) system," Energy, vol. 234, 2021, doi: 10.1016/j.energy.2021.121112.

[18] B. Guo, W. Javed, Y. S. Khoo, and B. Figgis, "Solar PV soiling mitigation by electrodynamic dust shield in field conditions," Solar Energy, vol. 188, 2019, doi: 10.1016/j.solener.2019.05.071.

[19] V. Gupta, M. Sharma, R. K. Pachauri, and K. N. Dinesh Babu, "Comprehensive review on effect of dust on solar photovoltaic system and mitigation techniques," Solar Energy, vol. 191. 2019. doi: 10.1016/j.solener.2019.08.079.

[20] A. A. Hachicha, I. Al-Sawafta, and Z. Said, "Impact of dust on the performance of solar photovoltaic (PV) systems under United Arab Emirates weather conditions," Renew Energy, vol. 141, 2019, doi: 10.1016/j.renene.2019.04.004.

[21] M. Hammoud, B. Shokr, A. Assi, J. Hallal, and P. Khoury, "Effect of dust cleaning on the enhancement of the power generation of a coastal PV-power plant at Zahrani Lebanon," Solar Energy, vol. 184, 2019, doi: 10.1016/j.solener.2019.04.005

[22] H. Ibbeken and R. Schleyer, "Development of the Chemical Composition of Sand," Source and Sediment, pp. 112–123, 1991, doi: 10.1007/978-3-642-76165-2_10.

[23] K. Ilse et al., "Techno-Economic Assessment of Soiling Losses and Mitigation Strategies for Solar Power Generation," Joule, vol. 3, no. 10. 2019. doi: 10.1016/j.joule.2019.08.019.

[24] R. J. Isaifan, D. Johnson, L. Ackermann, B. Figgis, and M. Ayoub, "Solar Energy Materials and Solar Cells Evaluation of the adhesion forces between dust particles and photovoltaic module surfaces," Sol. Energy Mater. Sol. Cells, vol. 191, no. March 2018, pp. 413–421, 2019, doi: 10.1016/j.solmat.2018.11.031.

[25] S. S. Jaafar and H. A. Maarof, "Influence of Micro-Controller-Based Single Axis Solar Tracker System on Solar Panel ' s Performance : Case Study Influence of Micro-Controller-Based Single Axis Solar Tracker System on Solar Panel ' s Performance : Case Study," no. September, 2022.

[26] M. Jaszczur et al., "The field experiments and model of the natural dust deposition effects on photovoltaic module efficiency," Environmental Science and Pollution Research, vol. 26, no. 9, 2019, doi: 10.1007/s11356-018-1970-x.

[27] M. Jaszczur, A. Koshti, W. Nawrot, and P. Sędor, "An investigation of the dust accumulation on photovoltaic panels," Environmental Science and Pollution Research, vol. 27, no. 2, 2020, doi: 10.1007/s11356-019-06742-2.

[28] W. Javed, B. Guo, B. Figgis, and B. Aïssa, "Dust potency in the context of solar photovoltaic (PV) soiling loss," Solar Energy, vol. 220, 2021, doi: 10.1016/j.solener.2021.04.015.

[29] H. Kawamoto and B. Guo, "Improvement of an electrostatic cleaning system for removal of dust from solar panels," J Electrostat, vol. 91, 2018, doi: 10.1016/j.elstat.2017.12.002.

[30] H. A. Kazem, A. H. A. Al-Waeli, M. T. Chaichan, and K. Sopian, "Modeling and experimental validation of dust impact on solar cell performance," Energy Sources, Part A: Recovery,

Utilization and Environmental Effects, 2022, doi: 10.1080/15567036.2021.2024922.

[31] H. A. Kazem and M. T. Chaichan, "The effect of dust accumulation and cleaning methods on PV panels' outcomes based on an experimental study of six locations in Northern Oman," Solar Energy, vol. 187, 2019, doi: 10.1016/j.solener.2019.05.036.

[32] H. A. Kazem, M. T. Chaichan, A. H. A. Al-Waeli, and K. Sopian, "A review of dust accumulation and cleaning methods for solar photovoltaic systems," Journal of Cleaner Production, vol. 276. 2020. doi: 10.1016/j.jclepro.2020.123187.

[33] A. Khodakaram-Tafti and M. Yaghoubi, "Experimental study on the effect of dust deposition on photovoltaic performance at various tilts in semi-arid environment," Sustainable Energy Technologies and Assessments, vol. 42, 2020, doi: 10.1016/j.seta.2020.100822.

[34] B. Laarabi, Y. el Baqqal, N. Rajasekar, and A. Barhdadi, "Updated review on soiling of solar photovoltaic systems Morocco and India contributions," Journal of Cleaner Production, vol. 311. 2021. doi: 10.1016/j.jclepro.2021.127608.

[35] X. Liu, S. Yue, L. Lu, and J. Li, "Investigation of the Dust Scaling Behaviour on Solar Photovoltaic Panels," J Clean Prod, vol. 295, 2021, doi: 10.1016/j.jclepro.2021.126391.

[36] R. D. Lorenz et al., "Scienti fi c Observations With the InSight Solar Arrays : Dust , Clouds , and Eclipses on Mars," vol. 200, no. June, pp. 1–12, 2019, doi: 10.1029/2019EA000992.

[37] F. M. Mahmood, S. S. Jaafar, and R. W. Mustafa, "Designing and programming a microcontroller based on a solar tracking system," vol. 3, no. 1, pp. 51–59, 2022.

[38] M. Memiche, C. Bouzian, A. Benzahia, and A. Moussi, "Effects of dust, soiling, aging, and weather conditions on photovoltaic system performances in a Saharan environment—Case study in Algeria," Global Energy Interconnection, vol. 3, no. 1, 2020, doi: 10.1016/j.gloei.2020.03.004.

[39] M. Mostefaoui, A. Ziane, A. Bouraiou, and S. Khelifi, "Effect of sand dust accumulation on photovoltaic performance in the Saharan environment: southern Algeria (Adrar)," Environmental Science and Pollution Research, vol. 26, no. 1, 2019, doi: 10.1007/s11356-018-3496-7.

[40] M. Mussard and M. Amara, "Performance of solar photovoltaic modules under arid climatic conditions: A review," Solar Energy, vol. 174. 2018. doi: 10.1016/j.solener.2018.08.071.

[41] R. J. Mustafa, M. R. Gomaa, M. Al-Dhaifallah, and H. Rezk, "Environmental impacts on the performance of solar photovoltaic systems," Sustainability (Switzerland), vol. 12, no. 2, 2020, doi: 10.3390/su12020608.

[42] F. L. G. Oliveira and M. I. R. Moreira, "CHEMICAL COMPOSITION OF CEMENT PORE SOLUTIONS," J. Japan Soc. Air Pollut., vol. 24, no. 1, pp. 45–51, 1989.

[43] M. F. Shaaban, A. Alarif, M. Mokhtar, U. Tariq, A. H. Osman, and A. R. Al-Ali, "A new data-based dust estimation unit for pv panels," Energies (Basel), vol. 13, no. 14, 2020, doi: 10.3390/en13143601.

[44] B. Parrott, P. Carrasco Zanini, A. Shehri, K. Kotsovos, and I. Gereige, "Automated, robotic dry-cleaning of solar panels in Thuwal, Saudi Arabia using a silicone rubber brush," Solar Energy, vol. 171, 2018, doi: 10.1016/j.solener.2018.06.104.

[45] M. Parthasarathy, "Challenges and emerging trends in toner waste recycling: A review," Recycling, vol. 6, no. 3. 2021. doi: 10.3390/recycling6030057.

[46] H. E. Redmond, K. D. Dial, and J. E. Thompson, "Light scattering and absorption by wind blown dust: Theory, measurement, and recent data," Aeolian Research, vol. 2, no. 1. 2010. doi: 10.1016/j.aeolia.2009.09.002.

[47] S. A. M. Said, G. Hassan, H. M. Walwil, and N. Al-Aqeeli, "The effect of environmental factors and dust accumulation on photovoltaic modules and dust-accumulation mitigation strategies," Renewable and Sustainable Energy Reviews, vol. 82. 2018. doi: 10.1016/j.rser.2017.09.042.

[48] H. Salimi, H. Ahmadi, D. Ashtiani, A. Mirabdolah, and R. Fazaeli, "Environmental Effects Experimental analysis and modeling of weather condition effects on photovoltaic systems ' performance : Tehran case study," Energy Sources, Part A Recover. Util. Environ. Eff., vol. 00, no. 00, pp. 1–13, 2020, doi: 10.1080/15567036.2020.1765902.

[49] A. Ullah, A. Amin, T. Haider, M. Saleem, and N. Z. Butt, "Investigation of soiling effects, dust chemistry and optimum cleaning schedule for PV modules in Lahore, Pakistan," Renew Energy, vol. 150, 2020, doi: 10.1016/j.renene.2019.12.090.

[50] P. Wang et al., "Reducing the effect of dust deposition on the generating efficiency of solar PV modules by super-hydrophobic films," Solar Energy, vol. 169, 2018, doi: 10.1016/j.solener.2017.12.052.

[51] L. Xingcai and N. Kun, "Effectively predict the solar radiation transmittance of dusty photovoltaic panels through Lambert-Beer law," Renew Energy, vol. 123, 2018, doi: 10.1016/j.renene.2018.02.046.

[52] S. Zakaria, Y. T. Mustafa, D. A. Mohammed, S. S. Ali, N. Al-Ansari, and S. Knutsson, "Estimation of annual harvested runoff at Sulaymaniyah Governorate, Kurdistan region of Iraq," Nat Sci (Irvine), vol. 05, no. 12, 2013, doi: 10.4236/ns.2013.512155.

[53] L. zhi Zhang, A. jian Pan, R. rong Cai, and H. Lu, "Indoor experiments of dust deposition reduction on solar cell covering glass by transparent super-hydrophobic coating with different tilt angles," Solar Energy, vol. 188, 2019, doi: 10.1016/j.solener.2019.07.026.

[54] X. Li, T. Liu, J. Wang, L. Xu, and Z. Zhang, "Dust deposition can focus light at a limited distance on photovoltaic panels," J Quant Spectrosc Radiat Transf, vol. 246, 2020, doi: 10.1016/j.jqsrt.2020.106921.