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Experimental Investigations of Dust Type Effect on Photovoltaic Systems in North Region, Oman

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Abstract— Solar energy advanced to occupy a significant place between the used energies of the near future. The operational principles of photovoltaic (PV) devices become more understood that led to an increase in the power conversion efficiencies of such devices. Solar cells or PV systems performance is affected by dust and dust storms highly impact the collected energy. Many studies showed that the accumulated dust reduces the performance of solar panels; however, these results were not clearly quantified.

The effects of dust on the performance of solar PV panels was the primary objective of this study, where six types of dust investigated from different areas of the North region of Oman (Al-Batinah region and Muscat). The study results show that the dust of Sohar and Saham has the biggest negative impact on PV performance because of their properties. The moisture content of saham is 52.21%, Sohar is 45% as the results showed. In the other hand, the dust from the other four locations was lighter and with lower moisture content. However, it is found that north region have less dust effect on PV performance comparing with other countries in the gulf region.

Index Terms— PV module, dust type, moisture, PV temperature, PV performance, Moh‘s Scale of Hardness

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1 Introduction

Solar photovoltaic (PV) industry is expanding worldwide,due to its technological and economic advantages [1]. The PV conversion efficiency ranges from 10 to 13% in commercial level. However, the outdoor installed PV modules efficiency may reduce by 10 to 25%. The reduction in the effectiveness referred to the losses in the inverter, wiring and dust pollution [2]. Any substance spreads in the air includes soil and dust particles (suspended dust), smoke, fog and particulate matters called dust. Dust formed from inorganic and organic substances of terrestrial origin [3]. Dust consists of substances like sand storms, bacteria, factories’ smoke, pollen, forest fires and volcanoes vapors. They also include the suspended solid atmospheric particles that remain in the air for long periods. These particles can transfer with wind movements for long distances [4].

The areas characterized by high dust concentration levels suffer from the significant losses due to dust pollution. Many valuable studies confirmed that the airborne dust deposition on the outdoor photovoltaic (PV) modules decrease the transmittance of the cell glazing.Also, itresults in a significant degradation of solar conversion efficiency of PV modules[5], [6]. The dust deposition on the outdoor PV studies focused on the glazing transparency performance. Ref. [7] studied the PV array output near Riyadh city in Saudi Arabia. The results indicated that a 32% reduction in energy output observed during the PV exposure to outdoor conditions about eight months. In the United Arab Emirates, El-Nashar [8] investigated the dust accumulation impact on the solar collectors’ performance for different periods. The study attested that the monthly glass transmissivity decline rate was between 10% in summer and 6% in winter. In Iraq adjacent to the formerly mentioned countries, Ref. [9] studied the desertic environmental conditions impact on the heliostats mirrors of CSP plant. The study revealed that primarily affected factor was the dust that accumulated on heliostats. Significant reductions were attained of 24, 12, 15 and 4% for spring, summer, autumn and winter seasons respectively. The decrease in the spring season was the highest due to the considerable dust storm reiteration during it.

Elminir [10] studied the impact of dust on the transmittance of glass samples fixed with different tilt angles. The study showed that the dust densities varied from 15.84 g/m^2 to 4.48 g/m^2 for tilt angles variation from 0^o to 90^o.Also, the results showed that the corresponding transmittance diminishedfrom 52.54% to12.38% respectively. Ref. [11] carried out an outdoor practical investigation Baghdad-Iraq to evaluate the dust pollution impact on the PV cells performance. The study results indicated that the dust and pollution deteriorated the PV cell performance, even with a short period exposure without cleaning. The dusty and polluted PV cells’ efficiency reduced about 12% compared to the clean cell.

Authors of reference [5] clarified that the dust settlement on PV systems dictated by two factors and these factors affected each other. These factors are the dust properties and the local environment. The dust properties mean the dust type (size, shape, weight, chemically, biologically and the electrostatic properties). These properties play a significant role in the dust accumulation/aggregation. The local environment includes the nature of human activitieson the site. Also, it includes the environment characteristics (surface finishes, orientation and height of installation) of the module [12]. Additionally, the impact of the environmental features as vegetation type and weather conditions affect the PV arrays performance. Qian [13] demonstrated that it is possible to accumulate dust on an (adhesive residues, rough, furry, electrostatic buildup) surface than a less sticky, smoother one. The initial accumulated dust tendsto attract or promote further dust settlement,

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whichmakes the polluted surface more amenable to dust accumulation.

Many techniques used to determine the dust particle sizes and morphology including commercial particle analyzers, scanning electron microscopy (SEM), and scanning probe microscopes. Optical microscope studies started in the 1970s led to the dust definition that its particle sizes are less than 500-μm diameter [14]. Young [15] was the first researcher used particle scattering theory who established relationships between the dust particle size and the scattered light and the resulted light transmission. Ju and Fu [16] modeled the particle size impact on the transmitted light, packing densities, and forces preserve the particles to the surface.

The dust compositions reflect the environments origin of the regions. The concentration and characteristics of elements could be used to define the nature of the main emission sources. The dust particles composed mostly of quartz and calciteaccompanied with smaller amounts of dolomite and clay minerals. Also, minor constituents of aluminum, iron, magnesium, potassium, and sodium, sulfur, nickel, vanadium, zinc, copper, and arsenic may appear. Samples from different locations in Iraq showed the particle size and the sand morphology varied from region to region [3]. Mohamed [17] observed from studying the Libyan Desert that the metrological conditions control the physical settlement and deposition rates. Also, it controls the particle size and periodic accumulation rates of dust. The study showed that dust particles transmittance indices depend mainly on its type (clay, sand, and organics) and the season of the year.

The aim of the recent study is to evaluate the effect of environmental conditions of northregion-Sultanate of Oman and the different locations in this area on the size and shape of the accumulated dust on PV arrays. Also, the paper target is to evaluate the dust accumulation on the PV performance.

2 PROBLEM STATEMENTS

Oman characterized by its specific location on the southeastern corner of the Arabian Peninsula in southwest Asia. It is positioned between Latitudes 16º 40´ and 26º 20´ North and Longitudes 51º 50´ and 59º 40´east. Sultanate of Oman has an area of 212,460 km^2 and a total coastline of 2092 square kilometers (Fig. 1). Oman total population is 3,174,000 in 2010, including 1,156,000 expatriate; thus the population density is around 9.3 inhabitants per square km. The annual population growth rate is about 4.4% [18]. The Omani economy depends heavily on the natural gas and oil sectors. The electrical power generation based primarily on natural gas. There are nine electricity companies generate and transmit electricity through all Oman. The peak electricity demand increased from 2773 MW in 2007 to 4634 MW in 2013 as shown in Fig. 2 [19], [20], [21]. All the generated power depends on fossil fuel whether natural gas or oil.

Oman has an excellent solar potential, however, its applications limited until 2008 to street lighting, traffic lights, the remote areas' telephones and pipelines' cathodic protection. The Omani government devoted a little funding for research and development of the renewable sector in the country [22]. Today, the Omani government is interesting in the growth of renewable energies sector to reduce the country's dependency on oil and natural gas resources. Oman tries to extend the oil and gas reserves life and to reduce carbon dioxide emissions. The Omani Government has conducted six pilot renewable energy projects from which four are solar projects [23]: A solar project in Hij of 100 kW PV; (ii) a solar project in Al Mazyonah with292 kW; (iv) a solar project in Al Mathfa of 28 kW; (v) a wind project in Masirah Island 500 kW; and (vi) a wind project in Saih Al Khairat, Wilyiat of Thumrait 4200 kW. The investment cost of these projects reached 8.1 million Omani Rial (1 OR= 2.57 US $). The renewable capacity of these projects is 6.6MW [24].

Al-Batina region consists of 12 provinces: Sohar, Al-Restaq, Al-Aawabi, Nakhal, Wadi Al-Maawel, Barka, Al-Masnaa, Al-Soweeq, Al-Khaboora, Saham, Loy, and Shnas. Al-Batina region lies on a vital geographical area on Oman See coast. This region extends from Khadma Melaha in the north to Ras Al-Hamra in the south. Al-Batina region restricted between the versants of the West Mountain and Oman Sea in the east. The even coast width reached about 25 km. The region populations are about 652,667 inhabitants as 2003 census. Sohar considered as the main industrial regional center with 230 km from the capital Muscat [24]. Sohar is the second largest city in Oman after Muscat, the capital. Ref. [18] claimed that Marmul is considered to have the highest solar radiation in Oman followed by Fahud, Sohar and QairoonHairiti. Solar radiation in Sohar Direct normal (DNI), diffuse horizontal (DHI) and global horizontal (GHI) irradiance has been measured and recorded experimentally. Fig. 2 shows a comparison between March and July 2013 measurements. It is clear seen that the irradiance is higher in summer (July) and promising to generate high and efficient energy. The highest irradiation recorded at the peak hour (13:00 hr) is 950 W/m^2 and the lowest is 202 W/m^2. If we compare solar irradiation in Sohar-Oman with that in Germany, since Germany is the PV user number one in the world, we will find that the lowest irradiation in Oman is higher than the maximum radiation in Germany (less than 190 W/m^2). However, we still need to know how much energy produces after degradation due to dust and temperature effects.

Fig. 1. Oman map

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Al- Batinah area topography made the region characterized with low dust storms taking advantages of the mountains protection (Al Hajar Mountains) and the sea. However, the region is surrounded by deserts that are a dust source, which affect the Batinah region sometimes. The dust in this region varies from one area to another depending on the local area dust, the dust storms origin, besides to the local climate conditions. The solar energy potential in Oman is relativity high in all of the parts of the country, because of its geographical location on the eastern edge of the Arabian Peninsula. The Omani climate is scorching, with maximum temperatures approaching 50 °C in the hot season, from May to September. Also, the climate of Oman is humid in the coastal region and remains dry in the desert. Desert areas have the highest solar potential while the coastal areas in the southern part of Oman have the lowest solar density [22]-[25].

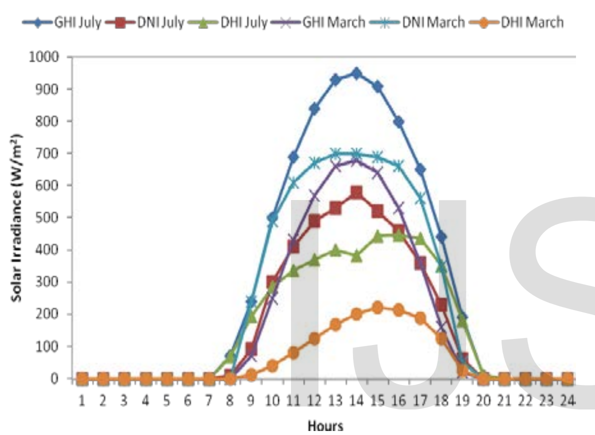

Fig. 2. Irradiance in Sohar on July and March 2013

3 Experimental Setup

In the recent study six samples of dust from variables areas in Al-Batinah region and Muscat tested, and its forms, shapes, and other specification inspected. The aim was to determine the dust type impact on the PV performance.

3.1 Samples Collection

Dust from different places in north region of Oman: Sohar, Liwa, Burka, Saham, Muscat, Al-Wasta, Al-Burimi collected for this study. The dust was collected from many cities on in the north coast of Oman to investigate dust type, shape, wet and weight and their effect on PV performance. All the dust samples collected from its accumulation of 1 m2 of horizontal glass left for four weeks. The samples underwent several tests to study their physical properties. A small plastic sheet was used to collect the dust every week.

3.2 Physical Characteristic of Dust in Al-Batinah Region

Various tests performed to inspect the physical properties of the dust. These tests are:

A. Specific Gravity

The specific gravity, Gs, is defined as the ratio of the density of a specified volume of material to an equal volume of water. Specific gravity tells how much heavier (or lighter) the material is than water. The specific gravity tests conducted following the BS 1377-2 [26]. The results of this test illustrated in Table 1.

B. Moh's Scale of Hardness

Moh's Hardness Test used for identifying mineral constitute of the dust. In this test, a comparison between the resistance of a mineral for scratching by ten reference minerals of known hardness and set as the Moh's Hardness Scale. The test applied to all collected samples, and the hardness found of all Al-Batinah region dust samples was less than 1.

Table 1
Specific gravity for dust samples (Gs)

City	G_s(unit less)
Sohar	2.2
Liwa	1.1
Barka	1.3
Saham	1.7
Al-Burimi	1.7
Muscat	1.29

C. Digital Microscope

50X zoom microscope employed to investigate the microscopic characteristics of all type of dust. Figs. 3 to 6represent part of the samples.

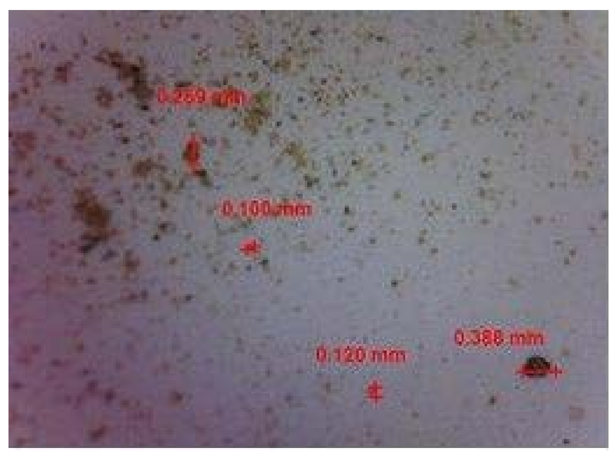

Fig. 3. Microscopic image of Sohar dust

D. Moisture content, plastic limit and liquid limit.

The moisture content of the soil and dust that is used to classify a fine-grained of dust according to the unified soil classification system or AASHTO system called the Atterberg limits. This experiment investigated moisture content, plastic limit, liquid limit, and plasticity index .It is representing the range of

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moisture content over which the dust is plastic. Once it is said plastic limit that means the moisture content, the range of moisture content at which over, the dust is plastic. So, plasticity index is the liquid limit minus the plastic limit. So, plasticity index shows the plastic state of the dust. Then, the liquid limit lies between the liquid state and the plastic state. Also, plastic limit lies between the plastic state and semi-solid state. This test applied to all samples; Table 2 shows the test results for Saham city as an example. Also, Figure 7 shows moisture content percentage versus the number of drop for Saham.

Fig. 4. Microscopic image of Liwa dust

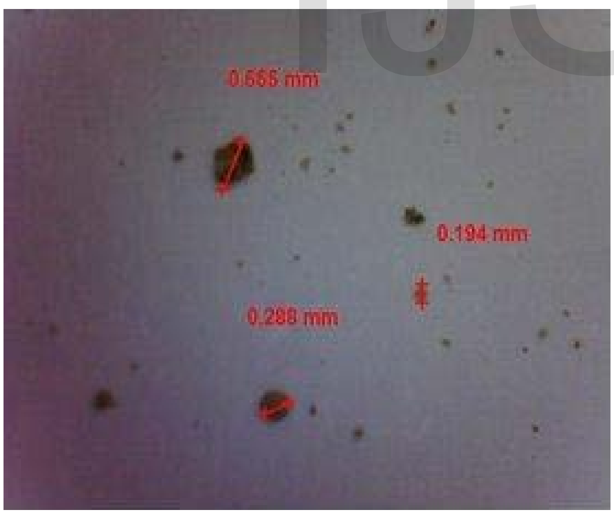

Fig. 5. Microscopic image of Saham dust

E. Sieves

Grain size analysis of dust containing relatively large particles is accomplished using sieves. A set of sieves with the specific sizes as Table 3 illustrates used to conduct the sieve analysis on a sieve shaker. The procedural steps of sieve analysis are under the BS 1377-2 [26]. Fig. 8 manifests the percentage passing vs. particles size. The tested dust showed a similarity in the size of all the microscopic images.

TABLE 2

VALUE OF LIQUID LIMIT OF SAHAM

Determination No.	1	2	3
Number of drops	12	37	63
Can No	A-1	A-2	A-3
Mass of can+ moist soil M(cws)	69.6	46.6	100
Mass of can + dry soil M(cs)	69	45	98
Mass of can Mc	66	42	96
M(w)= M(cws)-M(cs)	0.1	1.6	2
Ms=M(cs)-Mc	3	3	2
W= (M(w)/Ms)*100%	3.33%	53.3%	100%

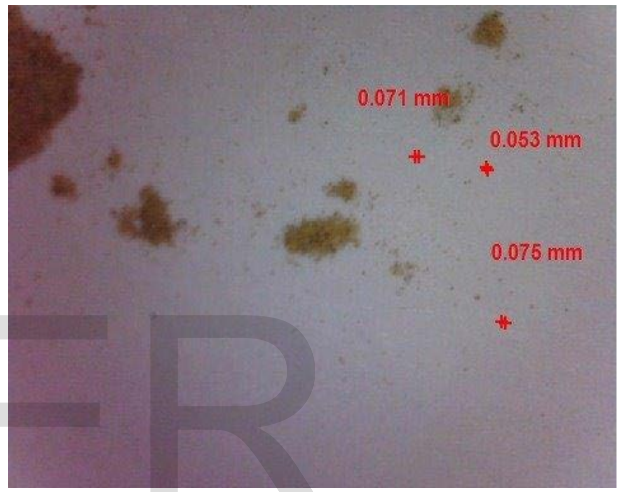

Fig. 6. Microscopic image of Muscat dust

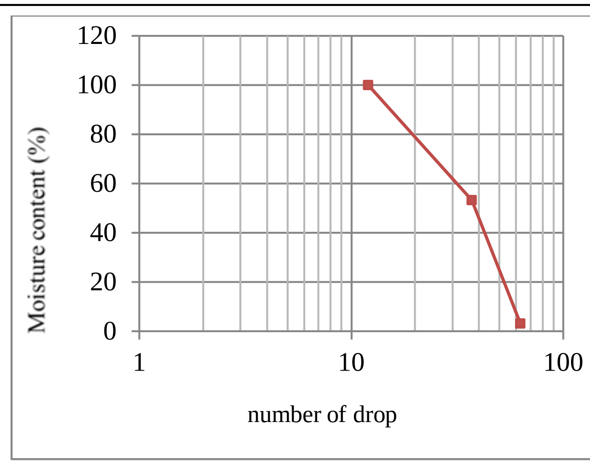

Fig. 7. Moisture content percentage vs. the number of drops for Saham. Liquid limit = moisture content at 25 drops = 70 %

Effect of Dust and Temperature on PV in Sohar

The effect of dust and temperature on mono-c PV performance tested in Sohar city as a part of Al-Batinah region. Three PV cells were located outdoor and used to conduct experiments for 30 days. The measurements carried out in these tests were voltage, current, power, ambient and module temperatures,

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and air humidity. The three systems were: dry and dirty panel, dry and clean panel, and cooled and cleaned panel (fan used for cooling).

TABLE 3
STANDARD SIEVES USED.

Sr. No.	Sieve Size	Sieve No.
1	3.35mm	6
2	2.36mm	8
3	2.00mm	10
4	600micron	30
5	425micron	40
6	300micron	50
7	212micron	70
8	150micron	100
9	75micron	200
10	63micron	230

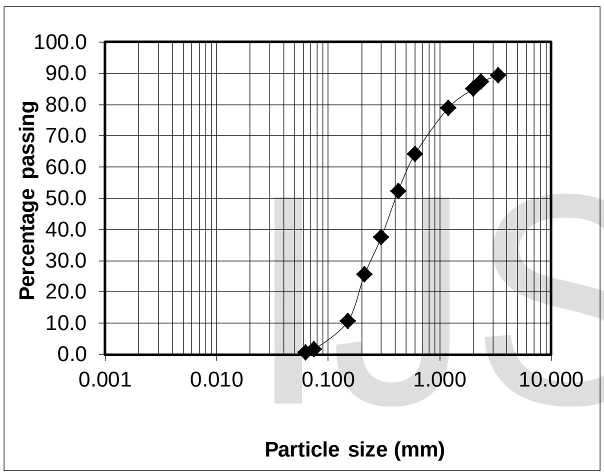

Fig. 8. Percentage passing vs. particles size

4 RESULTS AND DISCUSSIONS

The tests conducted in the former sections clarify several results. The values of specific gravity for Sohar, Saham, Liwa, Barka, Muscat and Al-Burimi are 2.2, 1.7, 1.1, 1.3, 1.29, and 1.7, respectively. All the values are very low except for Sohar dust. The dust from Saham, Barka, Liwa, Muscat and Al-Burimi is very light it can be removed easily by the wind or with cleaning. Light dust impact on the PV performance is very low compared to Sohar heavier dust. The moisture content for Liwa, Barka, Muscat and Al-Burimi were 24%, 26.3%, 35%, and 19%, respectively. Therefore, it considered low to moderate humidity. Moisture content for Sohar and Saham were as high as equal to 45% and 52.21%. This mean the dust from Sohar and Saham are a bit difficult to be cleaned because of its high humidity.

The hardness and grain analysis tests declared that the hardness of all type of dust is less than one and poorly graded dust. This dust is smooth, very fine and not hard, and then the dust does not cause cracks when it accumulates on PV. Table 4 shows the summary of the properties of all dust samples.

TABLE 4
SUMMARY OF THE PROPERTIES OF ALL TYPE OF DUST

city	Moisture content %	Plasticity index (PI)	Specific gravity (Gs)	Type of plasticity
Saham	52.21%	54.585	2.2	high
Sohar	45%	6.25	1.1	low
Barka	26.3%	4.32	1.3	low
Liwa	24%	4.22	1.7	low
Al-Burimi	19%	2.623	1.7	low
Muscat	35%	5.25	1.29	low

The dust particle pollution less than 10 micrometers in diameter (PM-10) measured in Sohar on July and March 2013. The standard values specified by National Ambient Air Quality Standards (NAAQS) to be 150 µg/m³ (24-hour average). In July, the weather is dustier (part of the day), hotter and more humid than in March. This situation adds another problem, which is a cement layer performed by dust and humidity that heated by hot weather on the PV surface. More investigations, analyze and recommendations needed in this field, to provide to the interested companies in investment in large-scale PV systems. Also, it is good to mention that Oman weather seems to be less dusty in comparison with UAE and KSA. The collected dust deposed on the PV system in Sohar-Oman found to contain: 0.2%, 36.1%, 44%, and 19.7% of C.Sand ("C" stands for clay or clayey soils), F.Sand (functionalized sand), Silt, and Clay respectively. It was not containing any ash particles and according to reference [12] it is recommended to clean the PV every 4-5 months.

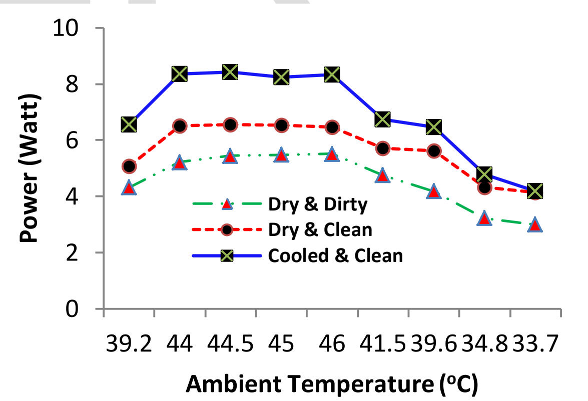

Fig. 9. The power variation with temperature for the three tested cases

Fig. 9 illustrates the results for the power variation with temperature. The pattern of PV power outputs follows very closely with the solar irradiance (normal distribution curve) which peaks at about 12:00-14:00 hr, as the figure declares. Also, the PV generates the highest power when it is clean and cool. Reduction in output power occur when it is dry and clean and more reduction when it is dry and dirty. Besides, Fig. 9 leads to the conclusion that even with an increase in ambient temperature the PV module has the maximum generated power when it is clean and cool. This discussion exhibits that the PV, significantly affected by temperature and dust. Cooling of the PV panel increased its efficiency by about 3% compared with un-cooled one. It is also possible to reduce the PV temperature more than10º C by putting pipes behind the cell for ventilation. Temperature reduction increased the panel efficiency that requires cooling the PV arrays at summertime.

5 Conclusions

The outdoor environmental dust accumulation on the panels of solar photovoltaic (PV) system is natural. There are studies showed that the accumulated dust can reduce the performance of solar panels. However, the results were not clearly quantified since it is geographical side specified. The objective of this study was to investigate the dust types, forms and shapes and dust samples from six cities from north region of Oman.

The outcomes of the recent survey are: the dust of Sohar and Saham has more moisture contents than the other samples. Sohar and Saham dust subject relatively more impact on PV performance because of their properties. The dust affected PV system in these areas more than the rest areas because their moisture content and plasticity index are relatively high. The dust in these places stick on PV and then it is hard to clean it. PV systems placed in Al-Buraimi have a little affection by the dust due to many reasons like moister content, plasticity index and specific gravity as we can see the results. Dust will affect the PV systems that will be placed in Liwa, Barka, and Mascut more than the cells placed in Al-Buraimi. However, the influence will be less than that for the PV systems in Sohar and Saham because the range of value of properties of dust in the middle. The results showed that dust properties in addition to temperature affect the PV systems and can reduce the system's efficiency. However, the situation of dust in Oman is the lowest effect on PV performance in the gulf region which sound promising of installs large scale PV systems.

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