Impact of Some Environmental Variables with Dust on Solar Photovoltaic (PV) Performance: Review and Research Status

Zeki Ahmed Darwish, Hussein A Kazem, K. Sopian, M.A.Alghoul and Miqdam T Chaichan

Abstract**—**Due to the energy crisis and growing demand for energy as the conventional energy sources have approached depleting and can't meet the world demand of energy. Fossil fuels have created plentiful environmental problems, such as global warming, acid rain, smog, water pollution... etc. Solar energy has the positive conditions as it is free from environmental pollutions, sustainable and requiring low maintenance. Solar energy can be collected to produce electricity by a variety of methods. Among these methods, photovoltaic PV systems have shown great success due to many reasons. Photovoltaic energy is preferred because it is clean, and secure. Therefore, a photovoltaic energy system will be one of the considerable sources of alternative energy for the current and future. PV systems performance depends on many factors, like geographical factors (latitude, longitude, and solar intensity), environmental ones (temperature, wind, humidity, pollution, dust, rain, etc.) and the type of PV used.

Studies proved that dust has significant influences the performance of the PV system. The dust accumulation on the surface of solar module causes decreasing in its performance. Dust particles differ in phase, sort, chemical and physical properties depending on many environmental conditions. Air temperature and humidity in addition to wind speed play a significant role in defining dispersed dust and how it will accumulates on the cell. As a result one can determine cleaning procedure. The important of this study came due to the transfer of large scale PV technology to the desert area in Arab countries. This area is hot and dusty most of the time and dust represent the main barrier to PV utilization. This paper revises the research in studying the impact of dust on PV system performance.

Keywords**—** Dust deposition effect, Photovoltaic, Air pollution, Temperature, Humidity, Air velocity.

I. Introduction

THE increasing concerns about rising fossil fuel prices and climate change highlights the interest in renewable energy which can play an important role in producing local, clean, and unlimited energy. Renewable energy includes any energy source that is replenished at least as fast as it is used. As examples of these renewable energies are ocean and tides energies, geothermal energy; biomass energy; hydroelectric power; wind power and sunlight energy [1].

The sun is humanity's oldest energy source that occupies scientists and engineers for hundreds of years to harness the power of sunlight for a wide range of applications as heating, lighting, and industrial tasks. Sunlight is an excellent energy source with consistent supply and inexhaustible. Solar energy also has several challenges, namely that it is only available during the day; it varies throughout the day and year, and is less energy dense than fossil fuels [2].

PV solar energy or more simply PV is one way to achieve solar energy usage. PV is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. The photovoltaic effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light [3].

Many publications cover silicon photovoltaic panels in several aspects. Solar cells are made of the same kinds of semiconductor materials used in the computer industry – typically silicon. Semiconductors can be used to transform sunlight into electricity because of their atomic structure. In typical PV installations, PV arrays are formed by connecting multiple PV modules in various configurations (i.e., series, parallel, series–parallel, etc.) [4].

Solar energy can be generated in large centralized plants covering hundreds of acres, such as the 14 MW installations at Nellis Air Force Base (AFB) in Nevada, or in smaller distributed applications of several kW, such as those on individual home roofs [5].

The output of PV is rated by manufacturers under Standard Test Conditions (STC), temperature = 25 ^{o}C; solar irradiance (intensity) = 1000 W/m^2, and solar spectrum as filtered by passing through 1.5 thickness of atmosphere. These conditions are easily recreated in a factory but the situation is different for outdoor. With the increasing use of PV systems it is vital to know what effect active meteorological parameters such as humidity, dust, temperature, wind speed; etc has on its efficiency. This paper investigates the effect of dust on PV system performance. Monto and Rohit have revised the effect of dust on PV performance based on two time periods: from 1940-1990 and 1990-2010 [6]. These studies revised the effect of dust based on the two periods while our paper discussed the

Zeki Ahmed Darwish is with the University Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia; e-mail: z_ahmed91@ yahoo.com).

Hussein A Kazem, is with Sohar University, Sohar, PO Box 44, PCI 311 Oman. (e-mail: h.kazem@soharuni.edu.om).

K Sopian. is with the University Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia; (e-mail: ksopian@eng.ukm.my).

M.A.Alghoul is with the University Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia; e-mail: dr.alghoul@ gmail.com).

Miqdam T Chaichan. is with the University of Technology, Baghdad, Iraq; (e-mail: miqdam1959@yahoo.com).

effect based on three main points: effect of dust properties, effect of PV system parameters and effects of environmental parameters. So investigation of the direct effect of dust and the other parameters added to the dust to produce compound effect is the aim of this paper.

II. Effect of Dust Propartıes

Solar energy has the favorable circumstances of being free from environmental pollutions, sustainable and requiring low maintenance. How-ever a solar photovoltaic (PV) and any solar energy systems depend strongly on geographical location and weather conditions. The operation of the PV system under real climatic conditions must be known [7].

The atmospheric condition in which substances are present at concentration higher than their normal ambient levels is called air pollution. Air pollution produces a harmful effect on man, animals, vegetations or materials [8]. These substances can be natural such as dust, or manmade. These chemical elements or compounds are capable of being airborne and can exist in the atmosphere as gases, liquids, or solid particles. Much attention has been shifted toward particles of size (both PM_{10} and $PM_{2.5}$) recently. It is known that particulate matter that is composed of various materials is mainly responsible for air pollution and stronger associations with health [9]. Particles which are smaller than 10μm can penetrate as far as the terminal bronchiole and alveoli, thereby adversely affecting the lungs function. These particles have many resources most of it are manmade. Millions and millions of tons of these particulates are emitted in to the air by automotives, trucks, power plants and…etc [10].

The PV application all over the world is facing many problems. One of the most important problems is the accumulation of atmospheric dust on the solar panels surface which causes decreasing its performance sharply [11]. This atmospheric dust have several effects on the use of photovoltaic power systems, including decreasing of the amount of sunlight reaching the surface and this leads to the decrease of the performance efficiency[12]. Al-Sudany in (2009) studied the effect of natural deposition of dust on solar panels under Baghdad environment, it was noted that the transmittance during one month, as an average decreased to, approximately, 50%. This result refers to the accumulation period as a strong effective parameter that causes a large decreasing in transmittance. This is due to the increasing of accumulated dust thickness with time [13].

Then the first point to be investigated is the effect of dust properties on the PV performance. This section separated into two main points: dust accumulation, and dust pollutant.

A. Dust Accumulation

Haeberlin et al in 1998 studied the accumulation of pollution by iron dust and other components at the edges of framed solar cell modules in Burgdorf. This accumulation caused a gradual reduction of output power of PV up to 8-10%. When the material of dust was analyzed the conclusion was that the dust in Burgdorf environment composed from iron oxide, silicon and some of organic materials [14].

Mazumder et al analyzed the dust deposition mechanisms on a solar module, the conclusions they deduced that the reduction in solar modules performance depends on the particle size, shape, distribution, deposition mechanisms and orientation of dust deposits on the module [15].

The relevant properties of lunar dust in USA were studied by Timothy et al in 2007, they specified three main problems which are dust adhesion, surface electric fields and dust transport. They conclude that mechanical adhesion resulted from the barbed shapes of the dust grains, and dust adhered to space suits both mechanically and electrostatically [16].

Sand and dust particles deposition on PV surface in dry region are presented with numerical and analytical models by Neil [17] and supported by a laboratory investigation of sand particles accumulation on a glass surface. The accumulation of sand particles on horizontal glass surface is found to exponentially reduce the available area for transmission of incident photons. A grain threshold algorithm in the software Gwyddion was used to determine the fractional area of glass covered by particles. Figure 1 shows that the available free area on the glass slide decreases with increasing amounts of sand both before and after a gentle disturbance caused the sand structures to settle. The rearrangement effect becomes more pronounced with increasing sand accumulation, as a result of clustering and the formation of upper layers of particles.

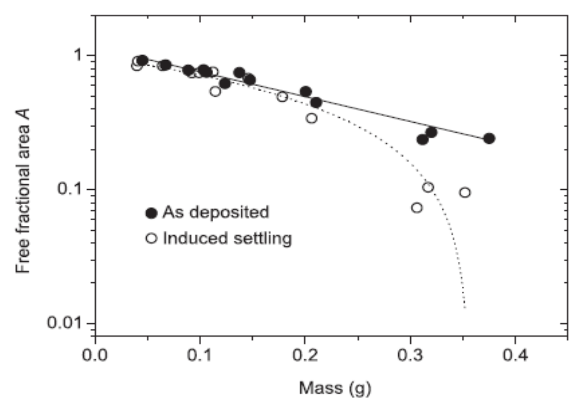

Fig. 1 reduction in the free fractional area of a glass slide with increasing quantities of sand [17].

Filled circles in figure 1 show the ash-deposited coverage while open circles show coverage after application of gentle disturbance to the glass slide. The solid and dotted lines are exponential and linear fits to the data respectively.

Initially all sand particles are distant from each other and subsequent particles landing on them cannot be supported and fall onto the glass. In this regime the free surface area decreases linearly with sand mass. As more particles arrive on the surface, clusters are gradually formed and there is an increasing probability that subsequent particles will land on a cluster rather than on the glass. This causes the evolution of the free surface area to deviate from the linear behaviour described by Al-Hasan [18]. The model which is describe this process, consider adding particles of an arbitrary shape to a slide. The total area of particles deposited as a fraction of the total area of the slide is N, and is directly proportional to their mass.

The free fractional area A is not simply $1-N$ because particles overlap. This behaviour can be represented mathematically taking into account the probability that small particles lands on free surface area is $1-A$, such that

$$\frac{dA}{dN}=1-A \Rightarrow A=1-e^{-N} \quad (1)$$

There are important differences however between this simple model and reality. In particular, it is clear that there is a limit to how closely grains can pack together and that some, but not all sand grains can support a second grain. Recalling that the close packing factor must be used to connect particle area N and filling fractions F_1 and F_2, the evolution of the layers (i) is described by

$$\alpha\frac{dF_1}{dN}=1-c(F_1) \quad (2)$$

$$\alpha\frac{dF_2}{dN}=c(F_1)[1-c(F_2)] \quad (3)$$

where α represent random close packing fraction ~ 0.8 and the fractional filling level of a given layer (i), (F_i) a layer can contribute to obscuring the surface is αF_i, $c(F_i)$ is the cluster function describe the fraction of sand grains that sit within a cluster. The total area is given by

$$A=1-\alpha F_1-(1-\alpha)F_2 \quad (4)$$

This model has been used to investigate dust accumulation in dry regions which are in quantitative agreement with laboratory investigation on particle accumulation on a glass slide.

Al-Sudany studied dust accumulation on PV system in Iraqi weathers and concluded that the dust accumulation on the surface of solar module causes decreasing in the performance about (35-65) % for one month accumulated time. In the dry weather the adhesive force between the dust atoms and the glass cover of solar module is the only reason for dust deposition, while, there are many layers of dust arise on the solar module surface in weather with high humidity [13].

B. Dust Pollutants

The air pollution is degradation of PV performance as a result to accumulation of solid particles varying in type, composition and shape. Kaldellis and Fragos [19] conducted an experimental study to compare the energy performance of two identical pairs of PV-panels; the first being clean and the second being artificially polluted with ash, i.e. a by-product of incomplete hydrocarbons' combustion mainly originating from thermal power stations and vehicular exhausts.

Figure 2 shows the impact of different mass deposition of ash on PV's energy performance which is decrease between the clean and polluted panels varying between 2.3% and 27% as it has recorded with time period of 1h.

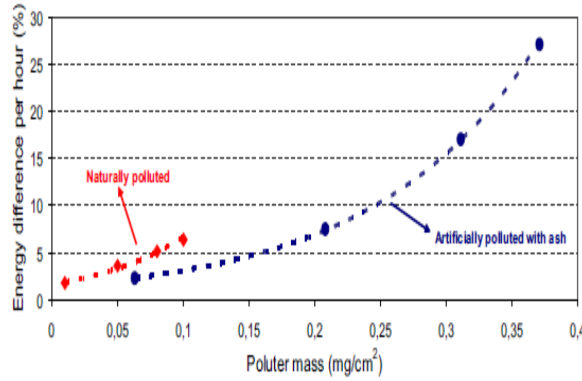

Fig. 2 Energy difference between clean and the polluted pair panel for various mass deposition in cases of naturally and artificially polluted PV [19].

Similar study by same authors [20], systematic experimental study of the pollution deposition was conducted to investigates the performance of two identical pairs of PV panels, the first panel being clean and the second being artificially polluted with three different type of air pollutants namely red soil, limestone and carbonaceous fly-ash particles. The experimental study was carried out under same environmental conditions as (ambient temperature, solar radiation, humidity etc,). According to the results obtained, it was found that the decreasing magnitude depending on the type of pollutant (i.e. composition, colour, diameter etc.). Based on the results, red soil deposition on PVs' surfaces causes the most considerable impact on PVs' performance and thus the highest generated energy reduction, followed first by the limestone and secondly by the carbon-based ash. Specifically, an amount of 0.35 g/m^2 of red soil deposition on PV-panels' surfaces may reduce the generated energy by almost 7.5% (compared with the respective of the clean one) while approximately the same deposition density for limestone 0.33 g/m^2 causes almost 4% energy reduction. On the other hand, even if almost doubling the pollutant mass for ash 0.63 g/m^2 the generated energy is decreased by only 2.3%. This may be explained due to the colour, composition and used diameter range of red soil causing the PV-panel to operate with lower performance.

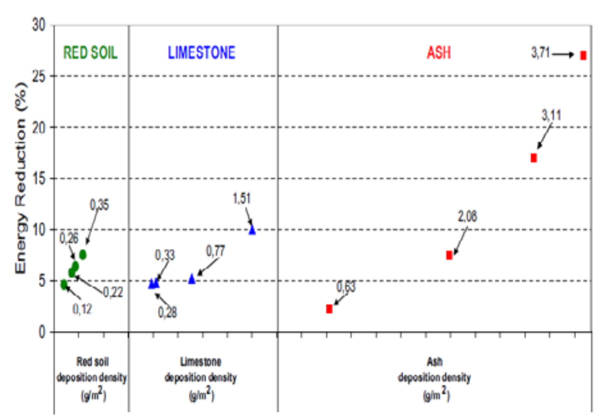

Fig. 3 Energy yield reduction of the polluted pair panel due to the different pollutants mass deposition in (g/m^2) [20]

Figure 3 shows the resulting energy yield reduction percentage between the clean "E_c" and the polluted "E_p" pair panel (adjusted in same tilt angle) as a function of different mass densities of red soil, limestone and carbon-based ash.

In Fig 3 there is a strong indication that red soil deposition on PV-panels leads to rather worse results compared with other two pollutants. It seems that the generated energy strongly reduces with the red soil deposition on PVs' surfaces while the effect is slightly smaller for limestone and considerably smaller for carbon-based ash.

Kazem et al [21] have investigated experimental the effect of three types of dust pollutants (red soil, ash and sand) on the performance of PV panels (mono-c, multi-c and a-Si technologies investigated). The authors claimed that ash have the highest effect in comparison with other pollutants. Also, it is found that a-Si is performing better than mono-c and multi-c in dusty environment as shown in Fig. 4.

Kaldellis and Kapsali [22] have developed a theoretical model in order to be used an analytical tool for obtaining reliable result concerning the expected effect of regional air pollution on PVs' performance. Air pollution represented by red soil, limestone and carbon-based ash related to previous study. In addition to, experimental concerning the dust effect on PVs' energy yield in a more polluted from air pollution urban environment is used to validate the proposed theoretical model.

Conversion efficiency "η" is defined as the ratio between the produced power "P_{out}" and the incident solar power "P_{solar}" available in collector's surface "A_c". Thus

$$\eta = \frac{P_{out}}{P_{solar}} = \frac{P_{out}}{A_c.G_T} = \frac{U.I}{A_c.G_T} \qquad (5)$$

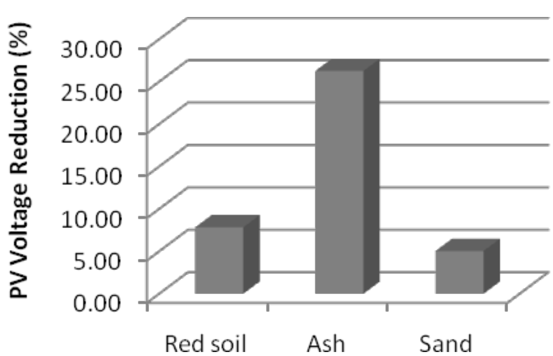

Fig. 4 Reduction in PV voltage due to the three pollutants [21]

where "G_T" being the corresponding total solar radiation. "I" current and "U" the output voltage normally comprising a function of time "t" in order to calculate the generated power of installation.

The dust deposition "ΔM "is expressed in g/m^2 ,via the PV collector area "A_C" , as;

$$\Delta M = \frac{\Delta m}{A_c} \qquad (6)$$

where Δm is the total mass of dust layer on the surface of the polluted pair of PV- panels.

Capacity factor "CF" (or energy yield) is defined as the ratio between the actual and rated output over a period time "Δt" as

$$CF = \frac{E_{\Delta t}}{P_P.\Delta t} \qquad (7)$$

where P_P is the peak power.

Energy yield reduction percentages between the clean "CF_0" and the polluted "CF" pair panel as a function of different mass deposition densities for red soil, limestone and carbon-based ash for each examine case is expressed as:

$$\Delta(CF) = \frac{CF_0 - CF}{CF_0} \times 100 = \frac{E_{cl} - E_{pol}}{E_{cl}} \times 100 = \Delta E \qquad (8)$$

Deposition of dust particles on the PV panels lead to an extra amount their energy performance, the rate of which depends strongly on the type of pollutant.

At this point, an attempt is made to simulate the PV-panels' energy yield (or capacity factor) drop on the basis of the air pollutant type (i.e. red soil, limestone and flying ash) and the corresponding specific mass deposition"ΔM ". In order to develop a reliable and practical relation an exponential function of the general form:

$$CF_j = CF.e^{-A_j.\Delta M_j} \qquad (9)$$

where "A_j" is the coefficient of standard deviation of mass measurements as in table 1 and the ranges between 0.06 and 0.24 depending on the type of pollutant "j", while "CF_j" is the capacity factor of polluted pair of panels for specific pollutant mass deposition "ΔM_j" (in g/m^2).

Table 1 Coefficient "A" and standard deviation

pollutant	A_j
Ash	0.06±0.024
Limestone	0.10±0.034
Red soil	0.24±0.085

In same context, the efficiency difference "$\Delta\eta$" between the polluted and the clean pair of PV-panels is defined as:

$$\Delta\eta_j = \frac{P_0}{G_T.A_C} - \frac{P_j}{G_T.A_C} = \frac{E_0 - E_j}{G_T.A_C.\Delta t} = \frac{(CF_0 - CF_j)}{G_T.A_C} = \frac{CF_0.P_P}{G_T.A_C} \qquad (10)$$

or equal

$$\Delta\eta_j = \eta_0.(1 - e^{-A_j.\Delta M_j}) \qquad (11)$$

In order to calculate the total capacity factor reduction percentage "$\Delta(CF)$" as a result to accumulation dust particles on the PV-panels surface one may combine Eqs. 9 and 8 into the following approach

$$\Delta(CF) = \frac{CF_0 - CF}{CF_0} \times 100 = (1 - e^{-A_{eq}.\Delta M}) \times 100 = \Delta E \quad (12)$$

with "ΔM" in (g/m^2) being the total mass of dust accumulated on PV-panel's surface and coefficient "A_{eq}" depending on the mass content of dust for each pollutant "ΔM_j", i.e:

$$A_{eq} = \sum w_j . A_j \quad (13)$$

$$w_j = \frac{\Delta M_j}{\Delta M} \quad (14)$$

and

$$\sum w_j = 1.0 \quad (15)$$

III. Effects of PV System Parameters

A. Effect of Tilt Angle

A tilt angle is one of the important factors that determine the performance of PV panels. In an experiment carried out in Roorkee by Grag [23] discovered that gather dust on a glass plate decrease transmittance by average of 8% after an exposure period of 10 days. Hegazy [24] studied dust deposition on glass plate with different tilt angles as well as measured the transmittance of the plate under different weather conditions. It was found that degradation in solar transmittance depend on the tilt angle. Also, the work by Sayigh et al [25] of dust deposition on a tilted glass plate located in Kuwait city were found to reduce the transmittance of the plate from 64% to 17% for tilt angles ranging from 0^0 to 60^0 respectively after 38 days of exposure to the environment.

New test methods and analytical procedures were provided by David in 1997 to characterize the performance of solar cell modules and arrays. The outdoor measurements of performance parameters under standard conditions and for all operating conditions were used. For the first time, the influences of irradiance, temperature, and tilt angle were studied. The empirical relationships obtained from the measurements can be used to improve the methods used for system design [26 &27].

B. Effect of PV Technology

PV module is classified into two categories which are silicon crystalline and thin film. Each category of PV modules (solar cells) contain of different types. The types of silicon crystalline are monocrystalline, polycrystalline; hybrid silicon, emitter wrap through cell and silicon crystalline investment while amorphous silicon, cadmium sulphide or telluride and copper indium disellenide or copper gallium are the types of thin film. The investigations found that a-Si performs best in dusty environment [28].

In 2006 Krauter et al provided a simulation program to examine the optical transmission of any solar cell modules under real-world conditions. The target was to compare various types of antireflection material and glazing of solar cell systems. They concluded that replacing the material of anti-reflection coating which has other refractive index causes an increase in solar module performance about 27% at incidence angle 80° [29].

C. Effect of Cleaning

Dust is probable to stick on to the array by Van der Waals adhesive forces. These forces are very strong at the dust particle sizes expected. Cleaning method must be overcome these forces. There are four ways classified to remove dust the surface of solar panel namely natural, mechanical, electro-mechanical and electrostatic. More investigation and ideas are important to reduce the effect of dust.

The simplest removal methods are the natural dust removal. The natural dust removal methods are rainfall and wind clearing. They can be made possible by simply choosing an array orientation other than horizontal [30].

The electrostatic dust removal is another method of dust removal. When the array surface is charged, the array will attract particles of opposite charge, and repel particles of the same charge [31].

Kasem used a new technique to reduce the amount of accumulated dust. Using movable platform attached to a solar tracking system of two-axis with photovoltaic's panels on the solar panel. The tracking system at the sunsets changed the direction of the solar panel from west to east for the horizontal axis (Azimuth). It also changed the tilt angle of the solar panel to become more than 90 (about 95) for the vertical axis (Altitude). This process was repeated daily at sunset to take advantage of this movement. The vibration will help to displace the deposited dust particles on solar panel surface. The comparison of this method with fixed solar panels that have fixed tilt angles of 30° and 45°was done. After 34 days of accumulation period the results indicated that the maximum losses in the output power was about 31.4% and 23.1% for fixed solar panels at tilt angle 30° and 45° respectively. While the losses in the output power for the solar panel with two-axis tracking system is about 8.5% [11].

IV. Effects of Environmental Parameters

A. Effect of Temperature with Dust

There are many researchers who are interested in the study of temperature effect on PV performance. In 1996 Kroposki et al calculated temperature coefficients for maximum current I_m, maximum power P_m, short circuit current I_{sc}, open circuit voltage V_{oc} and maximum voltage V_m for CdTe solar cell module. They showed that for the module and array data the current coefficients were considerably small; therefore, the current is not affected by temperature. In the same time, the voltage coefficients for both module and array were slightly negative, which means that the voltage is affected highly by temperature [32].

Increasing insulation level will made module's temperature rises rapidly due to the increase in ambient temperature which affects the energy dissipation of photons with energy values higher than semiconductor's energy gap [33].

The effect of temperature and series resistance for a crystalline silicon cell at two different light intensities was studied also. The series resistance is greater at higher temperatures and the temperature dependence of the low series resistance cell is relatively stronger at low light intensity, while the opposite is true for high series resistance cell [34].

Olchowik et al studied the effect of temperature on the efficiency of monocrystalline solar cell modules. They concluded that the efficiency of a monocrystalline Si solar cell module depends on the solar irradiance reaching its surface. Therefore, in order to increase the photo-conversion power of Si photo module, advantageous method is to use additional cooling systems [35].

The effect of operating temperature on the performance of amorphous Silicon (a-Si) solar cell modules under practical operating conditions was investigated by Astawa in 2007. The power production drop dramatically from autumn to winter period and the performance of solar cell modules also down about 65% of their initial performance in the same period [36].

In 2009 Erel used thermoelectric cooler to compare between the performance of solar cell before and after cooling. The result indicated that the decrease in solar cell temperature about 15 °C causes a gradual increase roughly to 0.01 volt for each (4Cm×4Cm) solar cell [37].

The investigations found that PV output power affected by ambient temperature. The more clean and cool PV the high power generated and more efficiency [38]-[39].

The temperature dependence of the voltage which decrease with increasing temperature (its temperature coefficient is negative) is very important. The voltage decrease of a silicon cell is about 2.3 mV per °C. The temperature variation effect on the current or the fill factor are less pronounced and usually neglected in the solar cell system design. Figure 5 shows the typical performance of the solar module at different cell temperatures. This is why only the voltage variation with temperature is allowed for practical calculations, and for individual module consisting of N_c cells connected in series is set equal to [40]:

$$V_{oc}=V_{oco}-(2.3N_cT_c) \quad (16)$$

Where V_{oco} is the open circuit voltage under standard test conditions (Irradiance = 1000 W/m^2, air mass (AM = 1.5) and cell temperature T_c = 25°C), N_c is the number of cells inside the module and T_c is the cell temperature which can be determined by using the following equation [40]:

$$T_c=T_a+ H_t((T_{Noc}-20)/0.8) \quad (17)$$

Where T_a is the ambient temperature, T_{Noc} is the normal operating cell temperature at open circuit with conditions: Irradiance equal to 0.8 kW/m^2, AM = 1.5, ambient temperature 20 °C and wind speed > 1m/s, and H_t is the total irradiance. In the design of the solar cell generator, the voltage will vary more than the current with irradiance. The operation of the module should lie as close as possible to the maximum power point [13].

B. Effect of Humidity with Dust

Study the effect of humidity on PV cell, two cases must take into account. The first case is the effect of water vapour particles on the irradiance level of sunlight and the second case is humidity ingression to the solar cell enclosure.

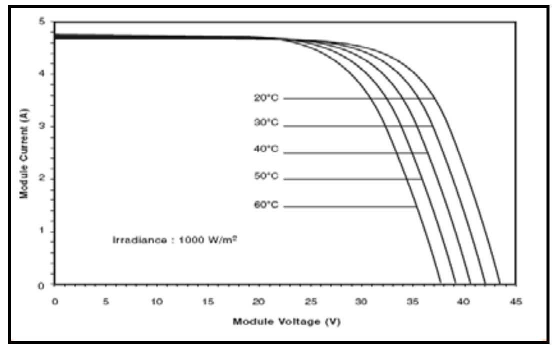

Fig. 5 temperature dependence of the I-V characteristics of a solar module [40].

Three phenomena occur when light hits water droplets. It may be refracted, reflected or diffracted. These effects deteriorate the reception level of direct component of solar radiation [41]-[42].

Kazem et al studied the effect of relative humidity on the performance of the Photovoltaic (PV). Three types of PV (Polycrystalline, Monocrystalline and Amorphous Silicon) were tested in this investigation. PV system connected to measurements humidity, current and voltage. The results showed that the output current, voltage, and power increase with low relative humidity. The efficiency of the PV is high when the humidity low. Hence low relative humidity enhances the performance of PV systems [43].

Figure 6 shows the effect of the relative humidity on the reception of visible solar radiation. It seem that this variation is non linear and this effect lead to little variation in V_{OC} and vast variation in I_{SC} as in Fig 7.

The clear influence of humidity on irradiance and I_{SC} lead to decrease in efficiency according to equation:

$$\eta = \frac{I_{sc-\max} . V_{oc-\max}}{A_C(irradinace\ level)} \quad (18)$$

where A_C is the effective area of the module, I_{sc} is the short circuit current , V_{oc} is the open circuit voltage and η is the conversion efficiency.

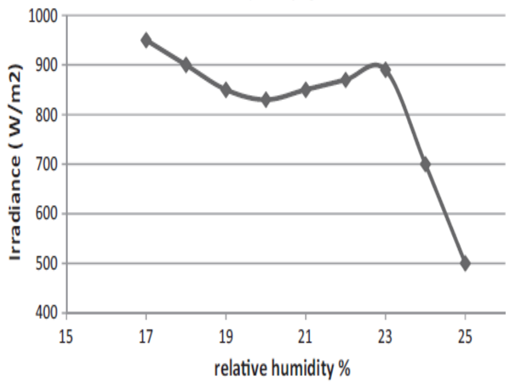

Fig. 6 variation of irradiance level with relative humidity [44]

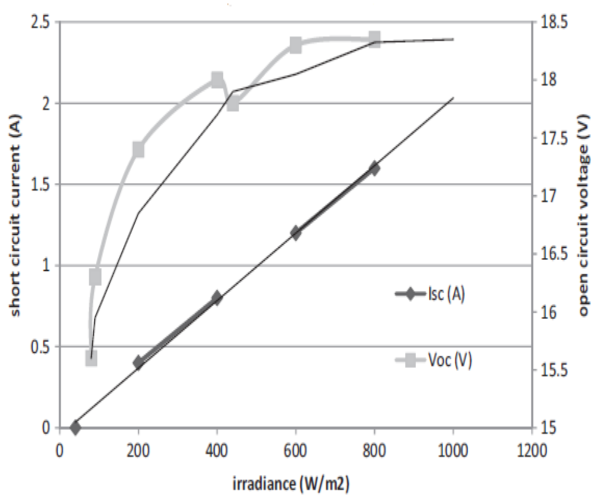

Fig. 7 variation of V_{OC} and I_{SC} with irradiance level [44]

The trend of wind speed has a reverse effect on relative humidity which in turn affects the received irradiance. For a long time exposure of PV modules to humidity leads to the ingress water into module and decrease performance [45].

In this context, delimitation with PV module is one of the most critical failure modes during service lifetime. Module of crystalline silicon most time fail at the cell interconnection or due to damaged cells while the thin film fail at scribe lines which is the dominate cause lead to modules degradation. Accordingly, thin films are sensitive to corrosive moisture while crystalline silicon cells are sensitive to embrillement of the encapsulated materials. Both of these degradation processes are increased by hot and humid weather [46]. The effect of dust increases in humid weather because they make together cement layer which make the cleaning process difficult task.

C. Effect of Wind Speed and Direction with Dust

Saw and Goosens [47] has used wind tunnel to determine the efficiency of sediment sampler designed to measure the deposition of aeolian dust. Marble Dust Collector (MDCO) and the inverted frisbee sampler were used in their investigation. Efficiency was ascertained for five wind velocities (range: 1–5 ms^{-1}) and eight grain size classes (range: 10–89 μm). They were presented formulate to determine the efficiency of an MDCO or frisbee when grain size composition of the sediment and wind's speed and direction are known. For the frisbee the equation:

$$E = au^6 + bu^5 + cu^4 + du^3 + eu^2 + fu + g \qquad (19)$$

where E = efficiency, u= wind speed (ms^{-1}), a, b, c, d, e, f, g numerical constant this formula validate to and wind between 0 and 7 ms^{-1}.

For the MDCO the equation:

$$E = p[\cos(2H) + q(4H)] + r \qquad (20)$$

where E = efficiency, H = orientation of the MDCO (rad); r, p, q are coefficients should be calculated. The last equation is validated to any speed between 1 and 7 ms^{-1}.

V. CONCLUSIONS

This paper reviews the effect of some environmental variables with dust on the PV performance. The evaluation on the status of research has been discussed based on effect of dust properties, effect of PV system parameters and effects of environment parameters. Research conducted according to this classification highlight the impact of dust on the performance of PV. Some points are deeply investigated and some are still need more study.

The main important points need more investigations are: dust properties (size, geometry, electrostatic deposition behavior), biological and electro-chemical properties of dust, optimization study, for various geographical/climatic locations (latitude) considering factor of optimum tilt, altitude and orientation for solar gain, prevalent wind patterns and minimum dust accumulation for various PV module configurations, dust particle geometry on its deposition behavior, electrostatic attraction on dust settlement behavior, impact of progressive water-stains on degrading the PV performance.

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