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Power loss due to soiling on solar panel: A review

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ABSTRACT

The power output delivered from a photovoltaic module highly depends on the amount of irradiance, which reaches the solar cells. Many factors determine the ideal output or optimum yield in a photovoltaic module. However, the environment is one of the contributing parameters which directly affect the photovoltaic performance. The authors review and evaluate key contributions to the understanding, performance effects, and mitigation of power loss due to soiling on a solar panel. Electrical characteristics of PV (Voltage and current) are discussed with respect to shading due to soiling. Shading due to soiling is divided in two categories, namely, soft shading such as air pollution, and hard shading which occurs when a solid such as accumulated dust blocks the sunlight. The result shows that soft shading affects the current provided by the PV module, but the voltage remains the same. In hard shading, the performance of the PV module depends on whether some cells are shaded or all cells of the PV module are shaded. If some cells are shaded, then as long as the unshaded cells receive solar irradiance, there will be some output although there will be a decrease in the voltage output of the PV module. This study also present a few cleaning method to prevent from dust accumulation on the surface of solar arrays.

Contents

1. Introduction

Solar energy, which comes from the sun in the form of solar irradiance, can be directly converted to electricity by using photovoltaic (PV) technology. PV technology uses solar cells made of semiconductors to absorb the irradiance from the sun and convert it to electrical energy. Currently, solar energy has drawn worldwide attention and is playing an essential role in providing clean and sustainable energy [1]. However, the research related to the nature of semiconductors, which are used in solar cells, has limited the efficiency of PV systems to 15–20%. Thus, in order to increase the efficiency of the PV system, some improvements such

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as applying sun trackers and maximum power point tracking controllers have been made to the PV system installation.

Solar panels are normally expected to be designed to produce the most ideal output or optimum yield. The factors that influence the determination of the ideal output or optimum yield can be classified into two categories, namely, changeable variables and unchangeable variables. The variables that can be changed provide design flexibility to respond to varying installation requirements, while the variables that are unchangeable need to be adapted to by default. The various changeable and unchangeable variables influence the configuration and design of a solar panel, the installation and operation of a solar panel and play an important part in solar panel generation. However, as more and more PV power plants are built in the upper MW and GW power ranges in the future, there is a need for more attention to be paid to this problematic area, which directly affects the efficiency of the power generation.

The characteristics of a PV module can be demonstrated by power–voltage or current–voltage curves. Fig. 1 shows the power–voltage curve of a PV module for different conditions of solar irradiance and cell temperature. As the figure shows, the PV output power is dependent on solar irradiance and cell temperature. Low irradiance leads to low power, and high temperature causes a reduction in output power. Furthermore, for each curve of the PV module, there is a point on the curve at which the PV module delivers maximum power to the load. This point is known as maximum power point (MPP) [2].

Solar irradiance and cell temperature are two factors, which affect the performance of a PV module. In addition to these factors, the amount of energy delivered by a PV module is dependent on other factors such as the reliability of other components of the overall system and other environmental conditions. This section provides a description of these factors [3,4].

A. ***Nameplate DC Rating****:* Also known as the sticker DC power rating is the maximum power output under Standard Test Conditions which solar module manufacturers indicate on their modules. However, there might an error between the Actual field performance and nameplate rating that can result from two issues. Measurement inaccuracy is one of potential source of error that can happen by the manufacturers while testing. Furthermore, first time exposition to sunlight can cause some modules to suffer from the light-induced degradation while becoming stable during the first few hours of their operation [3].

B. ***Diode and Connection loss****; the* primary application of bypass diodes is PV system is to preserve PV modules in partial shading conditions. Such a protective component can cause one form of connection loss known as power loss in the system. The other type connection loss in PV system happens where PV modules and other electrical components are connected together to form PV arrays, known as resistive loss [3]. Herrmann et al in 1997 did an investigation on hot spots in solar cells with respect to bypass diode. Because the series connection of the PV generator forces all the cells to operate having the same current (string current), the shaded cell within a module becomes reverse biased which leads to power dissipation in the form of heat [4].

C. ***Mismatch losses****:* When PV modules with different characteristics (*I* & *V*) are connected together they provide a total output power less than the power achieved by summing the output power provided by each of the modules. PV modules with same ratings coming out of one production line in a factory do not possess identical current–voltage characteristics for many reasons. This inequality causes PV modules to compromise on common voltage and current when they are connected in series or parallel in an array. This compromise results in a type of power losses known as mismatch losses which is recognized by several research works. Samad et al in 2014 studied mismatch loss minimization in photovoltaic arrays and suggested a solution based on arranging PV modules in arrays by genetic algorithm. Findings of this study show that a genetic algorithm-based arrangement of modules reduces mismatch losses more effective than classical modules sorting techniques do [5].

D. ***DC and AC Wiring:*** DC and AC wiring loss comprises of the resistive losses of the cables and wires used throughout the whole PV plant from the PV including the whole route from the PV module to the main power grid.

E. ***Sun-Tracking loss:*** Sun is moving across the sky during the day. In the case of fixed solar collectors, the projection of the collector area on the plane, which is perpendicular to the radiation direction, is given by function cosine of the angle of incidence. Sun tracking loss occurs when the single or dual axes of tracking solar panels are not set at the optimum orientation, or are misaligned due to a mechanical failure. In a study by Hossein Mousazadeh et al. in 2009, they reviewed principles of sun-tracking methods for maximizing PV output. They considered different types of sun-tracking systems. The most efficient and popular sun-tracking device was found to be in the form of polar-axis and azimuth/elevation types [6].

F. ***Shading losses:*** Shading loss occurs when PV modules are shaded by buildings, trees or other objects in proximity to PV modules. Since the output current of the PV module is a function

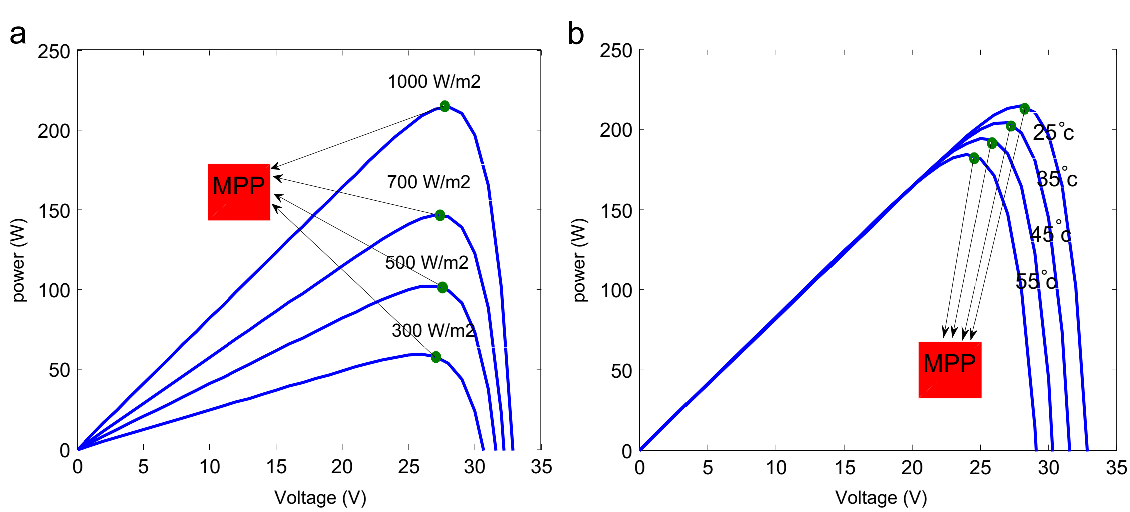

Fig. 1. *P–V* characteristics of a PV and location of the MPP for different irradiances at 25 °C, and (b) different temperatures at an irradiance of 1000 W/m^2.

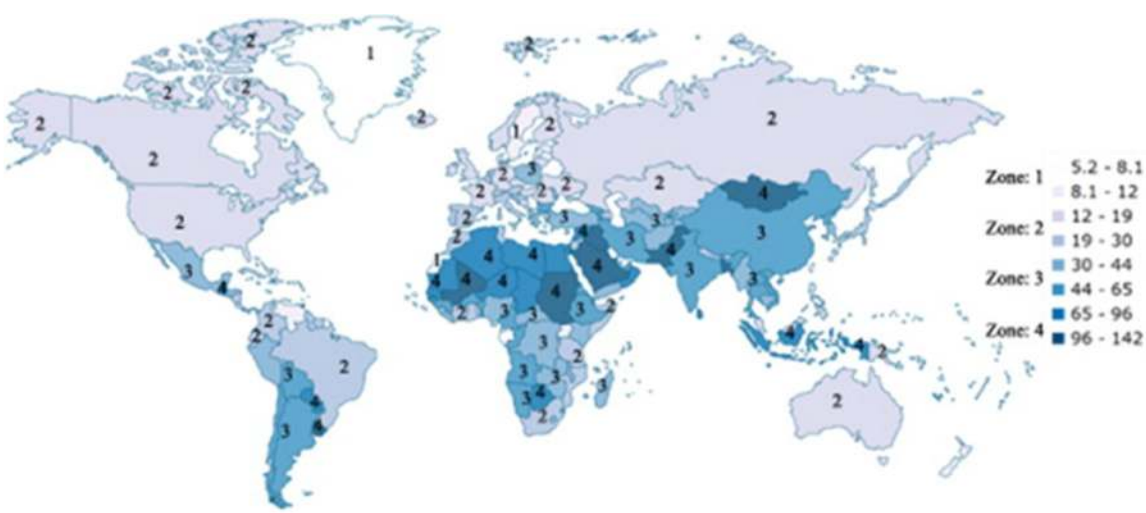

Fig. 2. Dust intensity around world.

of solar irradiance, a reduction in solar irradiance as a result of partial or complete shading will affect the performance of the PV module [3]. The PV system is troubled with a weakness of nonlinearity between current and voltage under partially shaded condition (OSC). According to statistic studies the power loss can vary from 10% to 70% due to PS [7].

G. ***Soiling losses:*** Soiling losses refer to loss in power resulting from snow, dirt, dust and other particles that cover the surface of the PV module. Dust is a thin layer that covers the surface of the solar array, and the typical dust particles are less than 10 μm in diameter but this depends on the location and its environment. Dust is generated from many sources such as pollution by wind, pedestrian volcanic eruptions,and vehicular movements among many others. The accumulated dust over time aggravates the soiling effect. In fact, the amount of accumulated dust on the surface of the PV module affects the overall energy delivered from the PV module on a daily, monthly, seasonal and annual basis. Sanaz Ghazi in 2014 investigate the pattern of dust distribution in different parts of the world is assessed and it was found that the Middle East and North Africa have the worst dust accumulation zones in the world [8]. Fig. 2 shows dust intensity in different colours around the world. The darker reigns indicate the higher level of dust. Travis Sarver et al. in 2012 [9] study introduced key contributions to the understanding, performance effects, and mitigation of these problems. These contributions span a technical history of almost seven decades. We also present an inclusive literature survey/assessment. The focus is on both transmissive surfaces (using for flat plate PV or for CPV) and reflective surfaces (heliostats or mirrors for concentrating power systems)

2. Critical studying in dust

There are numerous studies about photovoltaic performance. Although the efficiency of the PV system has increased trough many improvements, there are environmental and natural factors such as the deposition of soil, salt, bird droppings, snow, etc., on the PV module surfaces that can result in inefficiency in the performance of such systems. Thus, to ensure optimal efficiency and maximum energy yield, an in depth investigation to analyse the effect of dust on solar panels is necessary. In addition to analysing the effects that stem from such issues, this paper reviews the previous research done in this area to identify the noteworthy information.

A three-month test was performed by Hottel and Woertz [10] in an industrial area near a four-track railroad 90 m away from Boston, Massachusetts to investigate the effect of dust accumulation on solar panels. According to their findings, an average of 1% loss of incident solar radiation was resulted from dust that had accumulated on the surface of the solar panel with a tilt angle of 30°. During tis period, the highest degradation was found to be 4.7%. This lead the researchers to define a correction factor which is the ratio of the transmittance from an unclean or exposed glass plate to a clean one, of 0.99, with a 45° tilt angle. Surprisingly, this value was recognised in the design of conventional flat plate collectors until 1970.

Moreover, In 2001, Kimber et al. studied the effects of soiling on large grid-connected PV panels in California, United States. The study was mainly meant to provide a better model to predict soiling losses more precisely throughout the year. Prior to that, a constant annual value was the conventional assumption for soiling losses by many researchers. Furthermore, this study was meant to replace the characterization method of characterization of the effect of soil on PV that could be used only for a specific location rather than the entire region. A linear regression model was used to characterise soiling losses over the dry season. Out of 250 sites that were investigated, 46 were excluded because of the nonlinearity that had occurred in their data due to soiling behaviour and significant rainfall. A simulation was made to compare energy yield prediction with a model using only a constant annual soiling rate and a model with variable soiling rates random rainfalls. The conclusion was this study indicated an average daily efficiency reduction of 0.2% in days without rainfall in dry weather. Annual losses caused by this trend due to soiling ranges from 1.5% to 6.2% depending on the location of the PV plant. Moreover, it was found that the monthly yield simulation with the soiling data could provide a more accurate yield predictions than the simulation model with an assumed constant annual soiling loss. The data gathered from this study indicated some interesting facts about the effect of rain on PV modules. After a slight rain, the efficiency of some PV panels declined sharply, whereas the performance of other panels were improved. The authors concluded at least 20 mm rainfall is needed to clean the surface of PV system, otherwise the system will continue to experience power loss due to the dust and soil disposition.

Ali Kazem et al, reviewed the effect of dust on photovoltaic utilization in IRAQ. Their study was not limited to Iraqi geographical and meteorically characteristics but also they investigated the human activities that increased desertification in Iraqi areas that reflects on increasing sand and dust storms in the country. They also focused on dust accumulated causes, types and specifications that had priority in order to analyse its effects on PV systems. The aim of their study is to shows that Iraq has a very good potential for solar energy harnessing because of the long daily duration of sunshine hours and high levels of solar radiation. Recently The Iraqi researchers have perceived the high effect of dust storms which is accumulated on the surface of PV. The research investigated to know about causes for dust storms and how to prevent it. The Iraqi dust in urban area could form a source of pollution by heavy metals derived from three main sources:, automobile activities, industrial, and weathered material, via the concentration of Cd, Ni, Zn, Pb and Cr in street and household dust.

Zaki Ahmad et al. in 2014 [11] studied effect of dust pollutant type on PV. They highlighted a few points which were related to characteristics of dust on solar array. they found 15 types of dusts mentioned in different research including,, red soil, cement, ash, carbon, limestone, silica, calcium carbonate, sand, sand clay, soil, mud and coarser mode of air born dust, and Harmattan dust. From all this materials six of them have more significant effect on PV (ash, calcium, limestone, soil, sand and silica). They also found that effect of this Martials on PV characteristics is limited, in other word, most of the study considered artificial dust rather than natural dust accumulation. Ultimately, they suggested different pollutant types and different PV technologies should be investigated in future studies.

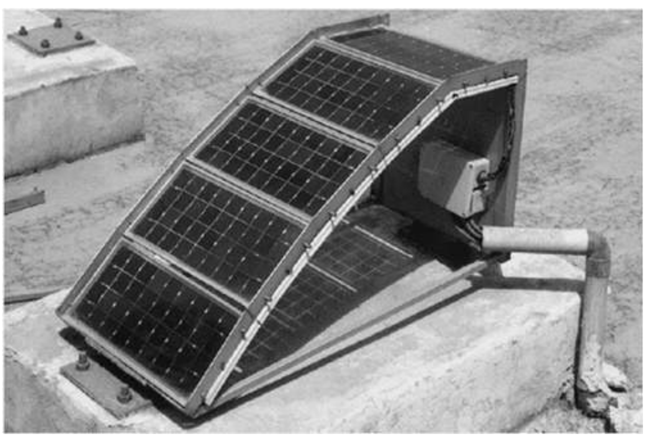

Fig. 3. PV system with different angle in Tehran.

In another study in 2013 the effect of haze pollution on two types of solar arrays (1 Kw) namely fixed flat photovoltaic and tracking flat photovoltaic under tropical climate were investigated. In the literature, they illustrated the different factors lead to power loss on photovoltaic arrays. One of the important factors in this study 2013 was haze pollution in Southeast Asia because of Indonesian forests burned to clear farm land and the resultant smoke blown by the wind to cover neighbouring countries. Power loss due to haze pollution has been considered before, after and during the haze pollution 2013 in this study. Data have been collected for 8 months from PV (voltage, current and temperature) and environment (temperature, irradiation, air pressure etc). Data was compared between both arrays and result shows that tracking flat photovoltaic more suitable rather than fixed flat [12].

In another study by E. Asl Soleimani and et al in Iran, Tehran in 1999, the investigation was on the effect of air pollution resulted from cars and local industries on the efficiency of PV system. In that experiment which was done on the roof of university of Tehran, several PV systems were installed with different tilt angles according to Fig. 3. The investigation shows that the output of the system varies with the season, and the reason is the amount of pollution that exists in the air in different seasons. In winter, due to the high density of the air, the pollution is the highest in the air and it affects the radiation, and as a results the efficiency reduces. In the fall, since the weather is windy the pollution goes away regularly and the output is higher than winter. In spring the system has the highest efficiency as the tilt angle increases since the

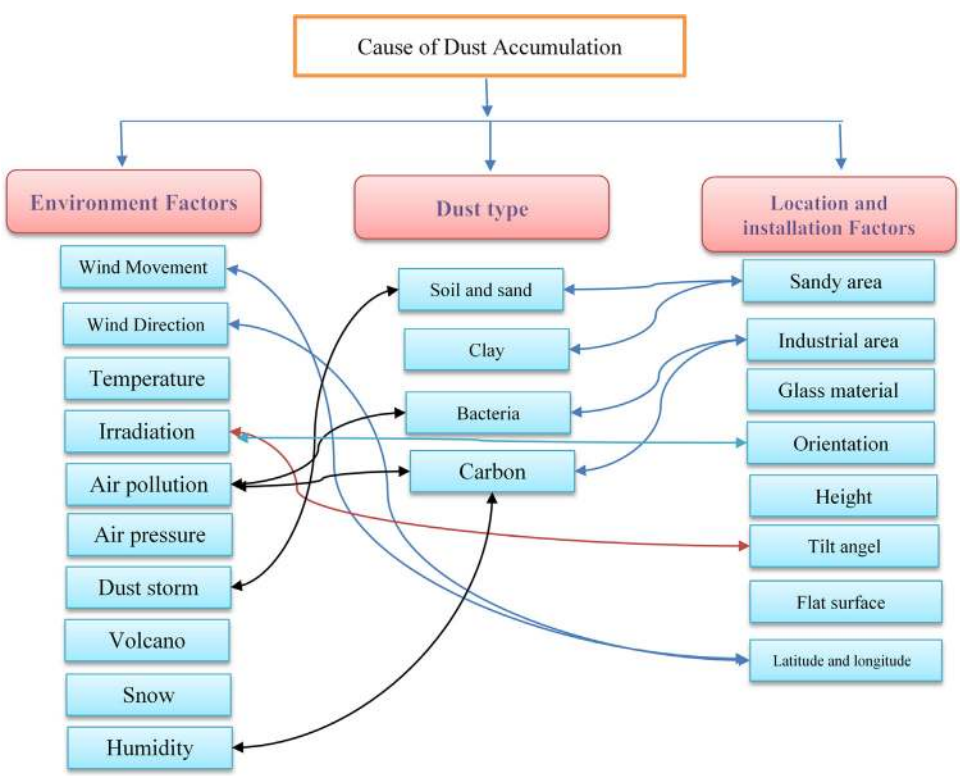

Fig. 4. Cause of dust accumulating on the surface of solar arrays.

Table 1
Dust accumulation on the surface of PV according to the location in literature.

Reign	Authors	Solar panel	T	Key point	Conditions
USA	Hottel and Woertz [10]	Solar thermal	3 m	Losses during this study around 4.7%	The angle of solar panel is 45°
	Dietz et al. [16]	Glass samples	3 m	Irradiation loss due to dust ard 5% reported	The angles design for this study between 0° and 50°
	Anagnostou and Forrestieri [17]	Photovoltaic module	1 y		Local condition is most damaging
	Hoffman et al. [18]	PV module	Lab	Test procedure for two field-related problems: surface soiling and encapsulate delaminating	
	Pettit et al. [19]	Mirror	1 m	The portable directional reflectometer used to measure the specular reflector loss due to dust accumulation can be limited to a single wavelength	Method to determine solar-averaged reflectance loss from a single measurement at 500 nm
	Blackmon and Curcija [20]	Heliostat	6 m	Washing heliostat by spray is feasible, and rain and snow could effectively clean it	
	Berg et al. [21]	Heliostat	5–6 w	Spraying the surface of PV can recover 95% of the reflectance losses	Using the mobile system for cleaning
	Freese et al. [22]	Mirrors	7	Reflecting can be decrease by many factors like wind. Rain and melting snow are effective in removing dust from PV	Useful correlations with wind, rain; cleaning cycle experiments
	Murphy and Forman [23]	Module (pv glass)	18 m	Evaluate of dust accumulation on the surface of PV	
	Hoffman et al. [24]	Module (pv glass)	17	Investigating the environment variable that increase dust accumulation	Outdoor exposure testing for long durations is the most effective means of evaluating soiling
	Roth et al. [25]	Mirror		Reflectance as function of particle size/scattering effects. Small particles are most significant scattering source ($<1\ \mu m$)	Reported effectiveness of surface coatings and electrostatic biasing for mitigation. Wind tunnel studies
	Cuddihy [26]	PV module	Theory	Describe known and postulated mechanism of soil retention on surfaces	Dust morphology/size data
	Pettit et al [27]	Mirror	10 m	Dust accumulation are much more effective in reflecting particles than absorbing it	
	Michalsky et al. [28]	Pyranometers	2 m	1% reduction for the exposed, not-cleaned pyranometer	
	Ryan et al. [29]	Solar array	6 y	Dirty solar array has 1.4% reduction each year.	
	Hammond et al. [30]	PV Glass	16 m to 5 y	Dust effect on solar panel increase as the tilt angle of incident increases. Power loss rise from 23% in normal incident to 4.7% 24° & 8% at 58° for radiometer,	Bird dropping one of the issues in this study
ASIA	Mekhilef et al. [31] Malaysia	PV Glass and cells	Lab 2-m	Investigated effect of dust on PV performance as function of tilt. Study show that average deduction in power output in different reign, for example power output reduce in Saudi 40% in Kuwait round 65%, Egypt 33–65% and in USA 1– 4.7%	Particles are including pollens, fungi, bacteria, vehicular & volcanic activity
	Jiang et al. [32] China	PV Glass		Soil accumulation layer 0 to 22 g/cm^2	Efficiency of PV reduce by 26%
	Sulaiman et al. [33] Malaysia	PV Glass	Lab	Dust accumulation reduce peak power around 18% e.	power loss difference between mud and talcum deposition
	Ju and Fu [34] China	PV Glass	1 y	Reduction during rainy season and dry season is 0.98 & 0.95 respectively.	In order to investigated dust effect the research divided into 3 phase the first one planning the second one is development and last is operation.
	Yerli et al. [35] Turkey	PV Glass		Dust and dirt and temperature are the factors that effected on PV performance	
	Mani et al. [14] India	PV Glass	review paper	Investigate on literature after 1960, identifying cleaning, environment factors	Suggested the best way for cleaning
	Kobayashi et al. [36] Tokyo Japan	PV Glass	Lab	The founding shows that degradation output of 80% or less with 3% of spot dirt on the PV module	
	Mastec bayeva et al. [37] India	PV Glass	1 m	During one month power output reduce from 87 to 75%.	
Middle east	Nimmo et al. [38] Saudi Arabia	Solar collector Glass& PV	6 m	Efficiency reduce 26% & 40% from solar collectors and PV module, respectively	
	Ibrahim et al. [39] Kuwait	PV cells	10 d	Voltage loss around 0.86% on other hand current reduce 13%.	Effect of shading investigated on solar cells.
	Alhamdan et al. [40] Saudi Arabia	Polyethylene covers	13 m	Irradiation was reduce around 9% within one month later after rain wash the surface reduce to 5% amount of loss.	Dust is soil and sand, dry condition
	Hassan et al. [41,42] Saudi Arabia	PV Glass	6 m	Efficiency reduce after 1 and 6 month by 33.5% and 65.8% respectively.	Dry area
	El-Nashar et al. [43] UAE	Solar collectors (glass)	1 year	Reduction in transmittance from 0.98 to 0.7,	Application is seawater distillation

Table 1 (*continued*)

Reign	Authors	Solar panel	T	Key point	Conditions
	El-Nashar et al. [44] UAE	Solar collector (glass)	1 year	Power reduce cause of dusty surface between 14%–18%.	Dry area, soil and sand
	Asl-Soleimani et al. [13], Iran	PV Glass	10 m	Energy output reduce around 60% by pollution in Tehran.	PV modules are design in different angle under air pollution
	El-Nashar [45] UAE	Evacuated-tube collector	1 y	Seasonal Glass transmittance is reduce 6 5 in winter and 10 5 in summer. Total loss without washing the PV after 1 year around 70%.	Data collected from PV hourly and monthly from solar panel.
	Alamoud et al [46] Saudi Arabia	PV Glass	1 y	Efficiency of PV reduce from 5.7% to 19%	Investigated on PV, module specifications to manufacturers' claims (differences). Hot, arid condition.
Euro	Zorrilla-Casanova et al. [14] Spain	PV Glass	1 y	Power output reduce during three month in dry season 20% and annual average deduction in PV were 4.4%.	
	Pravan et al. [47] Italy	PV Glass		Consider type of dust, cleaning methods, how to control loss in PV. Power output reduce around 6.9% with sandy soil and 1.1% with more compact soil	Investigated two 1-MW PV under STC. Regression model employed for consider different variable.
	Vivar et al. [48] Spain;	CPV	4 m	Dust reduce 26% power output in CPV and more effected than Flat PV.	CPV more effected than Flat PV system in dusty conditions.
	Becker et al. [49] Germany	PV cells	Lab	Air pollution reduce PV output around 4%	Air pollution cause of shadow in PV and decrease power output.
Africa	Elminir et al. [50] Egypt	PV Glass $ cell	7 m	Output power reduce around 17.4%	Investigate on tilt angle and dust chemical properties.
	Hegazy et al. [51] Egypt	PV Glass	1 y	Solar transmittance as function of tilt angles. Vertical panel had particles with diameters 1 μm. Power loss in transmittance typically 75–80% over a month's exposure	Compare the power output between Kuwait and India
	Adanuet et al. [52] Ghana	PV Glass	4 y	Dust materials in the air cause of decrease irradiation which is lead to reduce power output.	Suggested to cleaning the surface of PV

rainy weather washes the dirt down. Finally, in summer, the output is between fall and spring as tilting angle increases. It can be also observed that the 0 tilting angles and 23, in summer the efficiency of the system is the highest. and also they observed that the power output of a PV system decreased by more than 60% because of air pollution that covered the surface of the PV panel which obstructed the sunlight [13].

2.1. Cause of dust accumulation

There are two interdependent parameters that effect on characterization of soiling accumulation on solar panels, the property of dust and the local environment. Dust property consist of size, components, shape, and weight [14]. For example in Malaysia, the dust in acidic and can cause erosion to the surface of the panel. The local environment refers to the surroundings that the human activity has directly or indirectly created such as built environment, types of vegetation, and weather condition.

Furthermore, the surface is also a very important contributing factor in soiling process. If the surface is not smooth, and instead is rough, fury, sticky, and etc, it allows more soil to accumulate. The position of the panel which depends on the sunlight direction and wind is also important in soiling process. The more horizontal the surface is, the more dust can be accumulated. Besides, slow breeze also can result in dust accumulation whereas strong wind can clear the panel surface. However, airflow due to wind is able to effect the dust accumulation or dissipation at particular places of the solar panel [15]. The air speed is and pressure are not constant over the solar panel surface. In presence of a wind, wherever the airspeed is higher, there is lower pressure which can result in less soil accumulation and vice versa. Dust properties such a type, size, weight, and shape also play important role in dust scattering. Fig. 4 described different problems that result in soil accumulation on solar panel. It also shows the some factors has correlation which shows by error which need to investigate by future study. [14]. Table 1, compares soil effect various locations around the world. It can been seen in the table that majority of the studies are done in USA and Asian countries. Technically, Dust reduces output power from PV between 2% until 50% in different area. In Asian reign most of the dust martials is sand and soil and also in African countries dust come from desert area which accumulating on the surface.

3. Shading by soiling on PV performance

The term 'soiling' is used to describe the accumulation of snow, dirt, dust, leaves, pollen, and bird droppings on PV panels. The performance of a PV module decreases by surface soiling, and the PV power loss increases with an increase in the quantity of soil on the PV module. Thus, the accumulation of soil on the PV module can lead to a significant decrease in energy produced by the PV module. The condition becomes even worse in some situations such as snowfall on PV modules where snow completely covers the surface of the PV module, and no energy is produced at all [53].

3.1. Partial shading of PV module by a soil patch

In addition to energy reduction, some soil patches such as leaves, bird droppings and dirt patches that block some cells of a PV module but not the whole, have a severe effect on PV modules. Fig. 5 shows a PV module consisting of 10 cells and with one cell shaded and unable to produce any current. As the figure shows, in this condition the shaded cell acts as a resistance to current generated from the other cells. This causes the shaded cell to heat up and leads to a hot spot that can eventually damage the module [54,55].

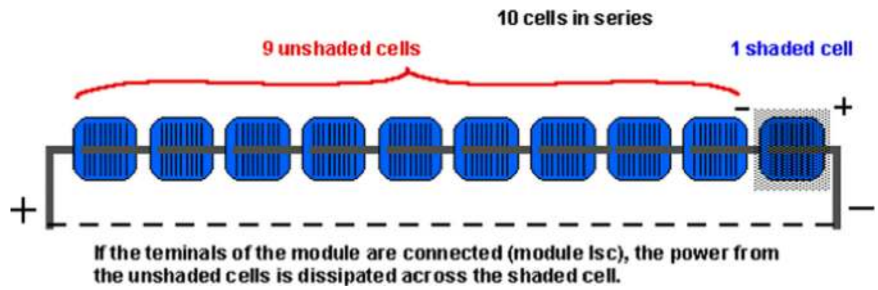

Fig. 5. Current flow through shaded cells.

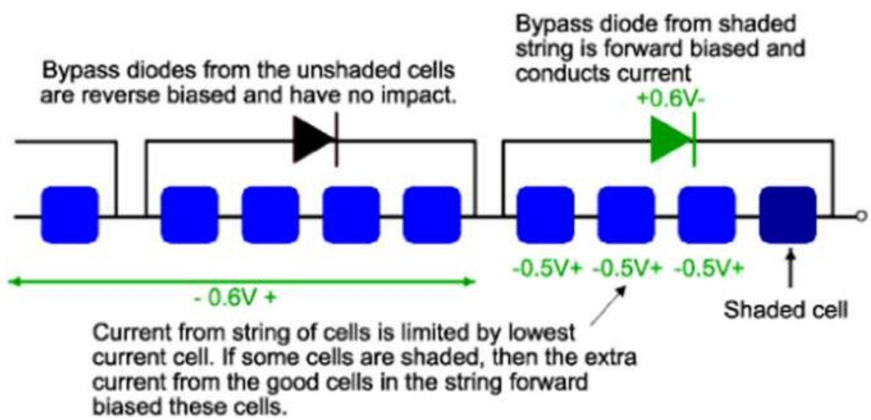

Fig. 6. Bypass diode in PV modules for hot spot avoidance.

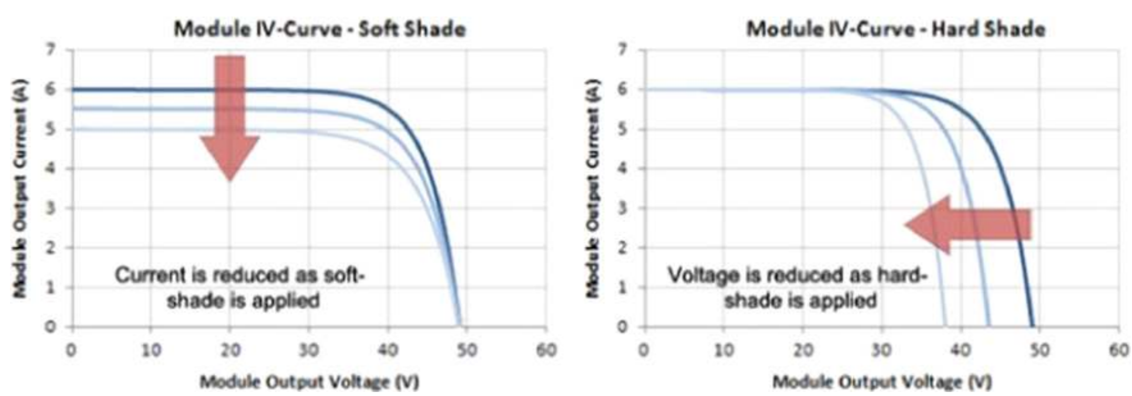

Fig. 7. Voltage–current characteristics of a PV module for soft and hard shading.

In crystalline silicone modules, bypass diodes are applied to solve the problem of partial shading. As shown in Fig. 6, if partial shading occurs, the current generated from unshaded cells passes through the bypass diode instead of the shaded cell. Thus, the bypass diode prevents the shaded cells from heating up and forming hot spots [53].

3.1.1. *The effect of soft shading and hard shading on module performance*

In general, there are two types of soil shading on PV modules, namely, hard shading and soft shading. Hard shading occurs when a solid such as accumulated dust blocks the sunlight in a clear and definable shape. On the other hand, soft shading takes place when some particles such as smog in the atmosphere or some dust on the surface of the PV modules reduces the overall intensity of the solar irradiance which is absorbed by solar cells. Each of these types of shading has a different effect on the PV modules. Soft shading affects the current of the PV module, but the voltage remains the same. For hard shading, the performance of the PV module depends on whether some cells are shaded or all cells of the PV module are shaded. If some cells are shaded, then as long as the unshaded cells receive some solar irradiance, there will be a current flow. As explained earlier, in this condition a partial shading hot spot condition may occur, but the problem can be solved by applying bypass diodes. In the case of hard shading, all of the cells of a PV module are shaded, and no power will be delivered by the PV module. Fig. 7 shows how each type of shading affects the voltage and current of a PV module, and Fig. 8 shows the voltage–power characteristic of the PV module for each shading condition.

As the figures show, for soft shading the voltage of the PV module will remain constant, and only the lower irradiance being absorbed by the solar cells leads to a decrease in current from the PV module. On the other hand, hard shading on some cells of a PV module will cause a decrease in voltage of the PV module, but because the unshaded cells still receive solar irradiance, the current will remain constant.

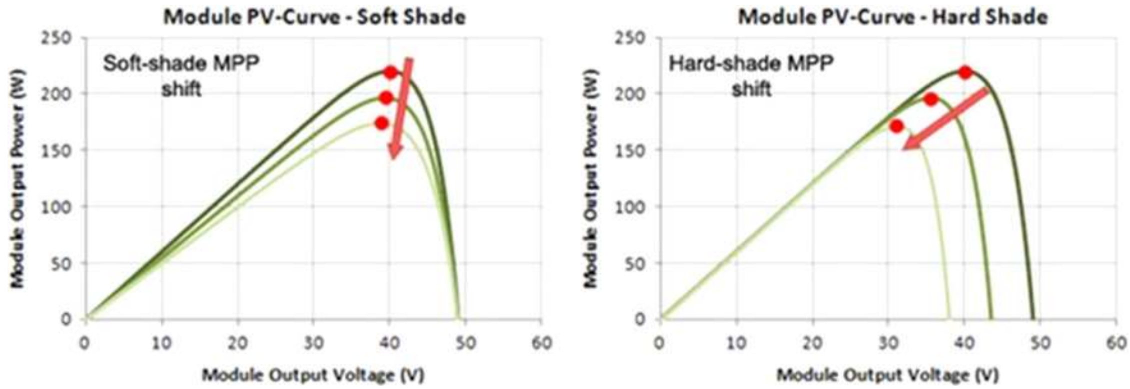

Fig. 8. Voltage–power characteristics of a PV module for soft and hard shading.

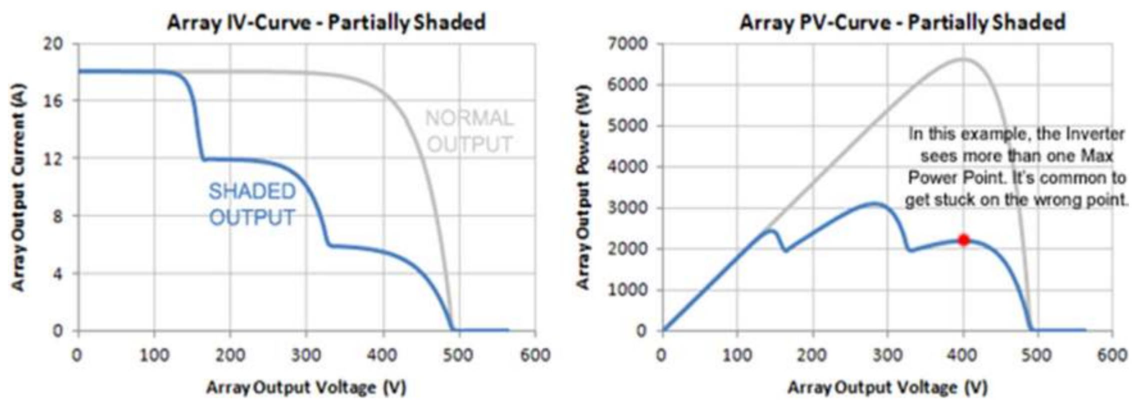

Fig. 9. Characteristics of the PV array under partial shading condition.

3.1.2. The effect of soft shading and hard shading on array performance

The effect of soft shading of soil on a single string array is the same as the PV module discussed earlier. However, in the case of more than one string in a PV array, the current imbalance in one string, which is as a result of shading, affects the other strings in parallel through the common inverter connected to the parallel strings. Hard dust on a surface of a PV array with single string will reduce the voltage of the string, but the inverter will detect this reduction and immediately regulate it. However, when there is uneven hard dust on different strings in parallel, a voltage mismatch occurs. In this condition, which is called partial shading, different parallel strings, which are connected to a common inverter, deliver different voltages to the inverter. This makes it difficult for the inverter to seek the optimum point of voltage at which the maximum power is delivered. Fig. 9 presents the voltage–current and voltage–power curves of a PV array under this condition.

However, solutions such as installing one micro-inverter for each string have been recommended to avoid these problems, although there are still some drawbacks with this solution such as the high expense and low efficiency.

4. Dust removal from PV (Solution)

Generally speaking, cleaning methods of photovoltaic surface has not been in the centre of attention among the researchers. This lack of attention can stem from the idea that the amount of rainfall in the region is sufficient to clean the PV surface. On contrary, soiling can have a sever effect on energy yield even in areas with significant rainfall. From review of literature and online sources, PV module cleaning methods can be categorized as follows:

Rainfalls are free of charge but seasonally volatile. Therefore, the reliability of this cleaning method is questionable especially when soiling is intensive and rainfall is not enough either in quantity or in intensity to wash off the soil. As mentioned in (Kimber et al. 2006), sharp declines in performance have been noticed in various cases after a light rainfall. Wind can also assist to reduce or eliminate soiling to a certain extent, but there is a need of water to clean the surface for optimum power generation.

Manual Cleaning: This method follows the same procedure that is used to clean windows of buildings. To scrub the soil off the surface, brushes with special bristles are designed to prevent scratching of the modules. Some brushes are also connected directly to a water supply to perform the washing and scrubbing concurrently. Out of reach, a ladder and a scrub with long handle might be needed.

Mobile Cleaners: this method utilizes machinery to perform the task and a storage for water supply or Sprinkler system is one of the best ways to clean the surface of the PV [53]. Mani et al. in 2010 review the recommended cleaning cycle to mitigate impact of dust, weekly cleaning during dry seasons and daily washing recommended for intensive dust accumulation.

5. Conclusions

Many factors determine the ideal output or optimum yield in a photovoltaic module. The environment is one of the contributing factors which directly affect photovoltaic performance. This paper has investigated the partial shading of a photovoltaic (PV) module by soil which has accumulated on the surface of the PV. The effect on the voltage (DC) and current (DC) were discussed for shading due to soiling. In general, there are two types of soil shading on PV modules, which are known as hard shading and soft shading. Soft shading takes place when some materials such as smog are in the air and hard shading occurs when a solid such as accumulated dust blocks the sunlight. The result shows that soft shading affects the current of the PV module, but the voltage remains the same. For hard shading, the performance of the PV module depends on whether some cells are shaded or all cells of the PV module are shaded. If some cells are shaded, then as long as the unshaded cells receive some solar irradiance, there will be decrease in voltage generated by the PV module. Recommended to improve the efficiency, weekly cleaning during dry seasons and daily washing recommended for in case of intensive dust accumulation. Analysis of physical aspects of solar panels and more importantly, shading effect as discussed herein could be incorporated into higher level projects and studies. Solar farms, smart cities with distributed solar generation systems [53], and rooftop solar panels at household level could be designed more efficiently considering the effect of shading and dust deposits.According to detailed overview presented in this paper, the following major conclusions can be summarized:

- The amount of accumulated dust on the surface of the PV module affects the overall energy delivered from the PV module on a daily, monthly, seasonal and annual basis.
- There are two interdependent parameters that effect on characterization of soiling accumulation on solar panels, the property of dust and the local environment.
- Sometimes soil patches such as leaves, bird droppings and dirt patches that block some cells of a PV module but not the whole, have a severe effect on PV modules.
- There are two types of soil shading on PV modules, namely, hard shading and soft shading.
- Many ways recommended to cleaning PV from dust accumulation.

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