Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
CODEN: JERDFO
Vol. 44, No. 6, pp. 251-262
Published Year 2021

The Environmental Effects on the Photovoltaic Panel Power: Jeddah Case Study

Mohammed AlJuhani[†,*], Mohamed R. Gomaa[‡,‡†,*], Talal S. Mandourah[†], Mowffaq M. A. Oreijah[†]

[†]Mechanical Engineering Department, Faculty of Engineering, Umm Al Qura University, Saudi Arabia
[‡]Mechanical Engineering Department, Faculty of Engineering, Al Hussein Bin Talal University, Jordon
[‡†]Mechanical Engineering Department, Benha Faculty of Engineering, Benha University, Benha, Egypt

*Corresponding Author Email: Behiri@bhit.bu.edu.eg; s44180495@st.uqu.edu.sa

ABSTRACT

This study aims to practically verify the effect of environmental factors on the solar cells efficiency, these factors that affect the performance of the cells have been tested, including the accumulation of dust on the cell surfaces, remnants of birds and/or birds dropping, in addition to the shadow caused by surrounding buildings or trees or so. This study was done on the rooftop of building in Jeddah, by putting four identical solar panels fixed on an iron stand then used the necessary equipment to carry out the measurements. The results showed that dust accumulated and dirt on the front glass of Photovoltaic (PV) panels had a significant impact on losing the electrical power generated by solar cells, so the solar cells should be cleaned regularly (monthly) especially in desert condition and depending on the severity of the weather conditions. One of the environmental factors that affected the performance of the PV cells are remnants of birds that partially blocked radiation from the sun. So, one should not overlook the importance of periodic cleaning of the solar cells to get the desired efficiency. The shading factor that partially blocked the sunlight from reaching the surface of the panels facing the sun had the highest influence of the efficiency of the PV cells and therefore the cells have to be placed in appropriate locations to allow for maximum efficiency.

KEYWORDS

Photovoltaic, PV Dust, Bird dropping, Fouling, Shadow, Photovoltaic performance, Solar Energy

INTRODUCTION

Photovoltaic energy generation has gotten a lot of coverage as one of the most exciting energy generation options. It can hold the world electricity consumptions. Over the last few years, the PV market has been rapidly expanding. PV panels made of silicon crystalline are commonly used in the world. Amorphous silicon (A-Si), Cadmium Telluride (CdTe), and Copper Indium Selenium (CIS) are examples of new PV developments that have lower processing costs than conventional silicon crystalline-based panels (CIS). New specifications and measurement schemes are now being established in order to be equivalent to new or upgraded technology. Photovoltaic can be recognized as one of the most promising renewable energy sources. Jeddah is located within the world solar belt and has more than 320 sunny days per year [1]. With the lack of conventional resources, Jeddah was forced to utilize abundant renewable energy recourses such as solar energy. Studies related to sun irradiation in the Jeddah site in Saudi Arabia introduce blessed with a high insulation during the year. The generated electricity could reach more than 10 GWh/year from 5 MW PV grid-connected power plant [2]. Companies started to invest and test many PV technologies to study large-scale projects known as the Kingdom's National Renewable Energy Program (NREP) project with a 300MWp initial capacity. The project target is to expand the capacity to 500 MWp in the future [3].

Because of the steady rise in power prices, domestic PV systems can now be used and installed at a lower cost than in previous years. Because of the noticeable drop in the PV system cost could compete the utility electricity price, particularly in high-irradiation areas like the solar belt. Many countries started to issue special legislation to encourage investing in PV projects. PV panels with the same rated power-even with the same technology- will not provide the same output power and energy yield. Also, the different thermal characteristics play an essential role in panel efficiency and output power because the PV panel is influenced by various environmental factors and solar cell physics. As a result, testing and modeling the PV module in the virtual environment and defining the influences of all significant variables are critical for ensuring system efficiency and performance [4,5]. Since a high penetration of PV output could cause grid instability, real-time power generation should be thoroughly investigated for grid efficiency [4-6]. The costs of the generated electricity from photovoltaics' decrease year by year. It is expected to be cheaper than conventional recourses, which leads the customers to install their PV systems instead of using the expensive traditional electricity from the utility [7]. In the future, real-time power, especially from domestic systems, will be more critical because higher penetration of PV systems will affect the grid performance. Furthermore, it is the basis of controlling energy management systems for smart homes. The photovoltaic performance models' uncertainty is still too high; early emerging PV performance models mainly dealt with ideal PV panel characteristics rather than complex conditions in the surrounding states [8]. Also, researches are primarily conducted for evaluating PV panel performance rather than system performance. In Jeddah, there is a lack of studies concerning the dynamic operation of PV panels and systems.

SOLAR ENERGY IN SAUDI ARABIA

- Solar radiation high numbers of 5.5-8 kWh/m^2 per day with approximately 300 days of sunshine per year.
- Total annual radiation 1650-2400 kWh / m^2, as shown in Figure 1.
- Solar water heaters: Financing Plan program is to increase the development of homes equipped Balskhanat share of 14% (the current situation) to 25% by 2015 and 30% by 2020.
- Photovoltaic cells: good use and experience of photovoltaic cells in the rural areas to generate electricity and pump water (about 1000 kW systems for photovoltaic cells) [9,10]. The five habited locations climatic zones are presented in Figure 1 [10].

Figure 1. Saudi Arabia climate zone.

Four types of solar PV systems, on-grid, grid service, off-grid, and hybrid solar PV systems, are available to fit better the area in which they are deployed [11].

PHOTOVOLTAIC CHARACTERISTIC

A PV panel's most significant electrical characteristics are I-V (current-volt) curve and P-V (power-volt) curve, I_{sc} (short circuit current), V_{oc} (open circuit voltage), the FF (fill factor), and the P_{max} (maximum output power). Figure 2 plays a standard current-voltage curve and the power-voltage curve computed from it and main points on both curves [12].

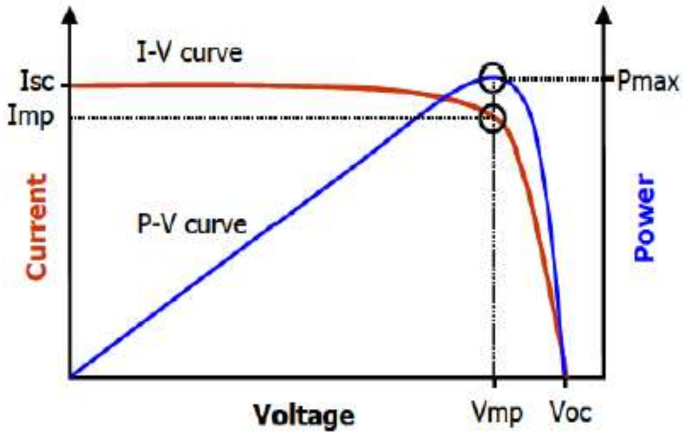

Figure 2. The curves of I-V and P-V of a photovoltaic module [12].

Irradiation and Temperature Effects

Incident irradiation affects the output power of photovoltaic cells. PV panel I_{sc} is proportional to incident irradiation, while V_{oc} grows exponentially to its maximal value as incident irradiation increases, and it varies marginally with light intensity [13-15]. The atmospheric temperature has a significant impact on panel temperature. As the PV panel temperature rises above the STC (Standard Test Condition) that is 25 °C, the short circuit current increases marginally. As the panel temperature reaches 25 °C, on the other hand, the V_{oc} is greatly influenced [14].

The Voltage in The Open Circuit and The Current In The Short Circuit

At any given condition, the V_{oc} (open circuit voltage) is calculated as follows, Equation (1):

$$V_{oc} = \frac{V_{OC_O}}{1+b\ \ln\frac{G_O}{G}}\left(\frac{T_O}{T}\right)^{\gamma} \quad (1)$$

Where V_{oc} refers to open-circuit voltage (V) at actual test solar irradiance G (W/m^2) and V_{oco} at the STC solar irradiance G_o (= 1000 W/m^2) [13,15].

It is simple to investigate I_{sc} (short-circuit current) by Equation (2) [16, 17]:

$$Isc\ =\ Isc_O\left(\frac{G}{G_O}\right)a \quad (2)$$

Where I_{sc} and I_{sco} are the short circuit current (A) under the actual tested solar irradiance G (W/m^2) and under the STC solar irradiance G_o (W/m^2), correspondingly.

The Fill Factor and Maximum Power

The greater the *FF* (fill factor), the better the power output. The *FF* is calculated as follows, Equation (3) [13,18]:

$$FF= (I_{mp}\, x V_{mp})/(I_{sc}\, x V_{oc}) \quad (3)$$

Where I_{mp} and V_{mp} are the current (A) and voltage (V) at the maximum point, respectively.

The solar irradiance and PV panel temperature have a significant impact on photovoltaic panel performance. The maximum power-output (P_{max}) of the PV panels is given by Equation (4) [6,13]:

$$P_{max} = V_{oc}\ x\ I_{sc}\ x\ FF \quad (4)$$

Where *FF* is the fill factor (-), I_{sc} is the short circuit current (A), and V_{oc} is the open-circuit voltage (V) of the solar PV module.

Module Efficiency

The PV module efficiency (η_{PV}) can be defined as converting solar irradiation (sunlight) into electricity. Mathematically, it predicted the module power output per unit area. The PV module maximum efficiency can be calculated by Equation (5):

$$\eta_{PV})_{max} = \left(\left(V_{mp} * I_{mp}\right)/(G * A)\right) * 100\% = \left(\left(P_{mp}\right)/(G * A)\right) * 100\% \quad (5)$$

Where *G* refers to global solar irradiation (W/m^2) and *A* refers to module area (m^2) [19-21].

STATEMENT OF PROBLEM

Due to the detrimental effect of several environmental factors on the solar PV systems especially in arid region and dusty, experimental investigation and analysis will be carried out using a PV system install above the house roof. Different parameter affecting on PV panel are studied in Jeddah, Saudi Arabia. The questions related to energy input, energy output, and efficiency of such systems will be attempted to answer.

EXPERIMENTAL SETUP

As a result of the oil shortage and rising demand for energy, traditional energy supplies are nearing depletion and cannot satisfy global energy demands. Fossil fuels have also caused extreme warming, acid rain, smog, water emissions, and other environmental issues. Solar energy has several advantages, including the fact that it is pollution-free, long-lasting, and low-maintenance. A variety of techniques may be used to capture solar energy to generate electricity. Photovoltaic PV systems have proven to be the most successful of these techniques for a variety of reasons. Consumers choose photovoltaic energy because it is renewable, safe, and moderately priced. As a result, photovoltaic energy systems will be one of the most important renewable energy sources in the present and future. The efficiency of a PV system is influenced by various variables, including geographic location (longitude, latitude, and solar intensity), environmental (temperature, humidity, wind, shading, pollution, and so on), and PV type.

EQUIPMENT AND EXPERIMENTAL PROCEDURE

This section describes the equipment that was utilized in the experimental investigation and how they connected.

Experimental System

In this research, four PV modules, each 160 W, p-Si panel with 36 cells connected in series, were used and adopted to construct the experimental set-up. As shown in Figure 3.

Figure 3. Four Polycrystalline PV's.

Table 1 summarizes the module's key characteristics.

Table 1. Characteristics of PV modules at STC (1000 W/m^2, AM1.5, 25 °C).

Photovoltaic modules BBS P-160W	
Maximum power (P_{mp})	160 W
Short circuit current (I_{sc})	9.04 A
Open circuit voltage (V_{oc})	22.8 V
Current at P_{max}	8.44 A
Voltage at P_{max}	18.95 V
Maximum reverse current	15 A
Operating temperature	-40 °C to +85 °C

DC Load Motor and Lambs

A direct current or DC load used in our experiment is four DC motor (140 W_p) that converts electrical energy into mechanical energy and eight LED bulb lamps (20 W_p). As seen in Figure 4.

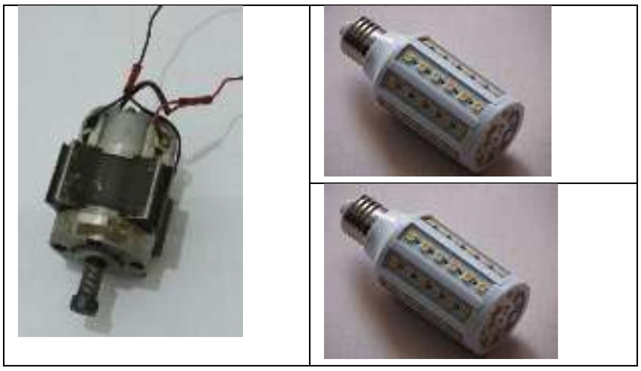

Figure 4. DC Motor (left) and LED Lambs (right)

Digital Multimeter

The digital multimeter device is used to measure the electrical parameters (current and voltage) and store all measurements each half an hour in memory. The short circuit (I_{sc}) and load (I_{load}) currents were monitored through a multimeter (accuracy ± 2% of reading 30 A). Also, the open circuit (V_{oc}) and load potential (V_{load}) were monitored through a multimeter (accuracy ± 0.5% of reading 400 V).

Irradiance Meter Survey 100 Instrument

The irradiance meter device that is used in the present work is SOLAR (survey 100) with (daily uncertainty < 3%). The device is put beside the PV panels with the same tilt angle. Therefore, the global solar irradiance is measured. The built-in ambient temperature sensor measures ambient temperature: the surface and back temperatures of the panels measured by an infrared thermometer. A thermo-anemometer measures the wind speed with a wind speed accuracy sensor 3 % ± 0.2 ms^{-1}.

UNCERTAINTY ANALYSIS

The experimental results measurements uncertainties of the electric current, voltage and power output are calculated according to the common and known method described by Kline and McClintock [21,23].

The PV modules output power can calculate by Equation (6):

$$P = I \times V \tag{6}$$

where V and I are the module voltage (V) and current (A), respectively. The uncertainty of the V and I are 16.7 V ± 0.5% and 7.04 A ± 2%, respectively. The nominal value of the power is 127.6 W. The uncertainty in this value is calculated and found to be 2.21 W or 1.7%.

INSTALLATION OF THE EXPERIMENTAL SYSTEM

The experimental setup is situated at the rooftop of my house in Jeddah with latitude (21.5° N) and longitude (39.2° E). This study was carried out for the period of March and Abril month; the period of each experiment measurement was 3-day sequential. The data collection was complex and took longer than the planned time because this study was carried out in the Spring months, where the weather of many days was cloudy and dusty, which made it extra challenging to experiment. Four Polycrystalline (p-Si) PV are used in the present study that is installed on galvanized steel stand with front high (0.7 m) and back high (1.3 m). These PV's faced the south direction with a recommended optimal fix tilt angle equal (25°). One of these PV's set as a reference with no effect on it and the other one was affected by the environmental induced conditions upon it. In this study, the impact of three environmental effects on PV was conducted; dust accumulation, Bird droppings, and shading.

Effect of Dust Accumulation

The deposition of dust on the surface of solar panels is a significant source of concern, particularly in desert areas where dust storms occur regularly. The amount of solar irradiation hitting the cells decreases as dust accumulates on the surface of the PV panel, reducing the glass cover transmittance. The volume of dust that collects on the surface of the glass reduces its transmittance. The amount of dust that collects on the glass's surface of PV determines how much it transmits light, the angle of inclination, exposure period, and climatic conditions at the location. Four polycrystalline modules are installed at actual outdoor conditions and tested for several days. The temperature, volt and current, and power output are monitored daily every half hour. Until the results are taken, one of these modules is carefully cleaned. It will be a reference PV panel. The other PV panels are affected by dust (dusty).

Effect of Birds Droppings

Bird droppings assist in blocking sunshine from touching and reaching the solar cells. The more soil and bird dropping (dirt) they have, the less energy they generate. Many factors affect the panel output power produced, whereas the dirty (dust and bird dropping) panel is the biggest one but the simplest to repair. According to most experts, solar panels that are polluted do not contain as much energy as clean panels. According to the NREL (National Renewable Energy Laboratory), these losses may be as high as 25% in some regions. Some dealers have registered losses of up to 30% for consumers who have never cleaned their panels [23].

Effect of Shading

One of the most common essential causes of losses in a PV configuration is the shading of PV panels. In reality, shading 10% of a system's area will result in a 50% reduction in inefficiency. The string architecture is to blame for this excessive impact. If one shaded panel is present in the array, the entire string underperforms. Inverters may find a new optimum power point or have one inverter per panel, among other technological solutions. Many technical solutions involve inverters finding a unique maximum power point or having one inverter per panel. However, the only way is to prevent partial shading as far as possible [24]. The impact of shade on a PV panel's output is influenced by factors such as; insolation reduction, panels that do or don't have by-pass diodes, PV array circuit architecture (series and/or strings in parallel connection). In this experiment, several shadow rates have been tested on a PV module with 36 p-Si solar cells connected. The impact of shadow rate on the majority of critical PV module characteristics has been investigated.

EXPERIMENTAL PROCEDURE

The performance of the PV system was monitored on selected days in March and Abril 2021. The measurement equipment was chosen based on the values that are wanted to study the variables that this study aims for. Before buying the appropriate measurement equipment, the properties were analyzed based on the specifications of the PV cells and choosing the proper load, DC motor. Then it was tested in a lab to make sure it can contain the maximum current and voltage that comes out of these cells. The other equipment's were bough based on the standard of best precision possible with the chance of its availability in the market. All experiments had a similar procedure of connection types of equipment and data collection, as shown in Figure 5. The difference was the type of impact that affected on PV module.

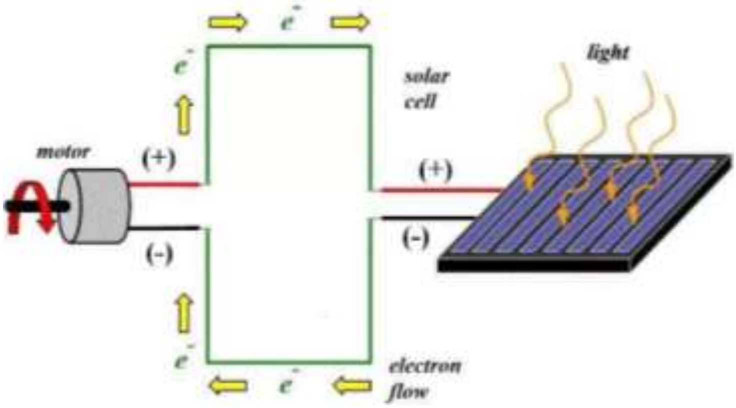

Figure 5. Electric circuit of Photovoltaic module connected to dc motor.

MEASUREMENT STEPS

The following is the entire experiment procedure:

1) Put the irradiance meter instrument above the PV module to determine the amount of irradiation per unit area. And at the same time, determine the ambient and PV temperature by thermocouple wires of irradiance meter.
2) PV panel open circuit voltage (V_{oc}) and short circuit current are measured with a digital multimeter.
3) When connected the DC motor to the PV panel, the motor will be loaded and rotated.
4) Using pliers to stop the rotation of the motor, then measure the load current (I_{Load}) and Load voltage (V_{Load}).
5) The infrared thermometer device is used to measure the temperature of the PV backside.

These steps are done for four PV modules separately. And all results are recorded on several tables to draw the curve.

RESULT AND DISCUSSION

The electrical performance obtained of four PV systems for an average value of different days' period are monitored to investigate the effects of the atmosphere on the performance of PV modules and how this impacted the output characteristic.

RESULTS OF DUST ACCUMULATION EXPERIMENT

The comparison between reference PV and dust accumulation PV modules in terms of the load power output evolution during the day is illustrated in Figure 6.

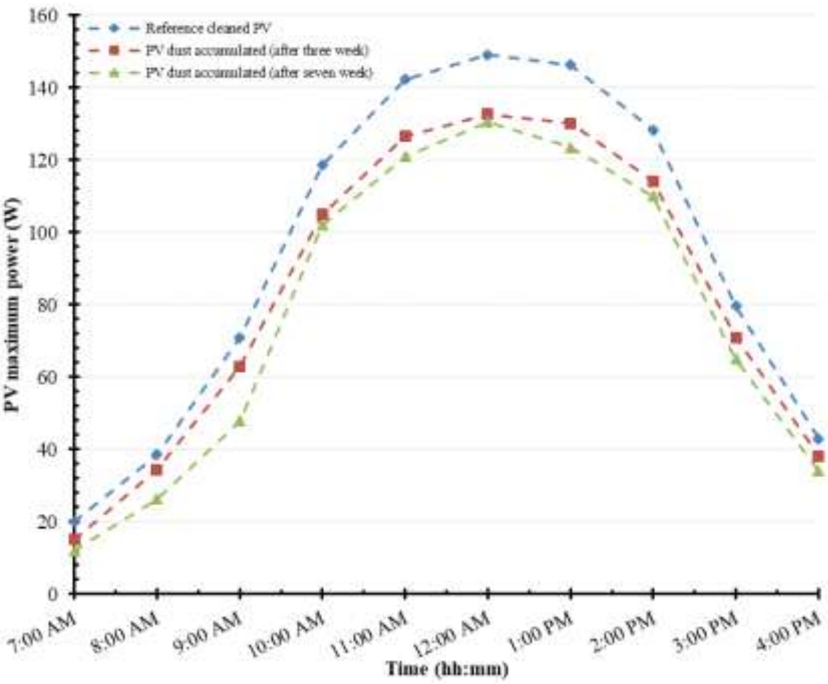

Figure 6. Reference PV vs. dust accumulation PV modules: a comparison in terms of the load power output.

The figure depicts the variation in load power production (which influences the PV electrical performance) of both reference and dust PV. The output power from the reference PV is higher than the dusty PV. The maximum power can calculate as Equation (7);

$$P_{max}=V_{oc}*I_{sc}*FF \tag{7}$$

The following formula was used in calculating the solar panel efficiency as Equation (8);

$$\eta = ((V_{oc}*I_{sc}*FF)/(A*I)) \tag{8}$$

Where, V_{oc} is the open circuit voltage (V), I_{sc} is the short circuit current resulted by the PV module (A), *FF* is the fill factor, A is the solar panel area (m^2), and *I* is the intensity of solar irradiation (W/m^2).

The reduction in power can be defined as Equation (10);

$$\text{Reduction in power} = \left(\frac{power\ without\ dust-power\ with\ dust}{power\ without\ dust}\right) \tag{9}$$

The output power for reference PV (without dust) at noon is 144.5 W, whereas the power output for dusty PV at noon after one week without cleaning is 126.3 W. From Equation (9), the power reduction is 12.6 %.

Also, the reduction in efficiency can be defined as Equation (10);

$$\text{Reduction in efficiency} = \left(\frac{\eta\ without\ dust-\eta\ with\ dust}{\eta\ without\ dust}\right) \tag{10}$$

Using Equation (3) in section one, the FF found to be equal to 0.72.

The calculated reference PV (without dust) efficiency using Equation (5) has given a value equal to (13.86%) and the efficiency of dust PV (12.3%). So, the efficiency reduction is 11.86%. A similar conclusion also obtained by reference [6,25], investigating the effect of dust on solar photovoltaic systems, has shown that over the period of 108-day, the PV efficiency dropped from 7.2 percent to 5.6 percent. The impact of dust on the output of solar PV panels investigated in Ref. [26], studied the effect of dust on the performance of solar PV panel has reported that the average efficiency (4.34%) without dust and average efficiency (0.49 %) with dust, which presented a reduction in efficiency by 89%.

RESULTS OF BIRDS DROPPINGS EFFECT

The effect of Birds droppings on the output PV module power is investigated. The results presented in Figure 7 possibly suggest that the birds dropping may be considered a small form of shading, which blocked the sun rays that reached PV cells.

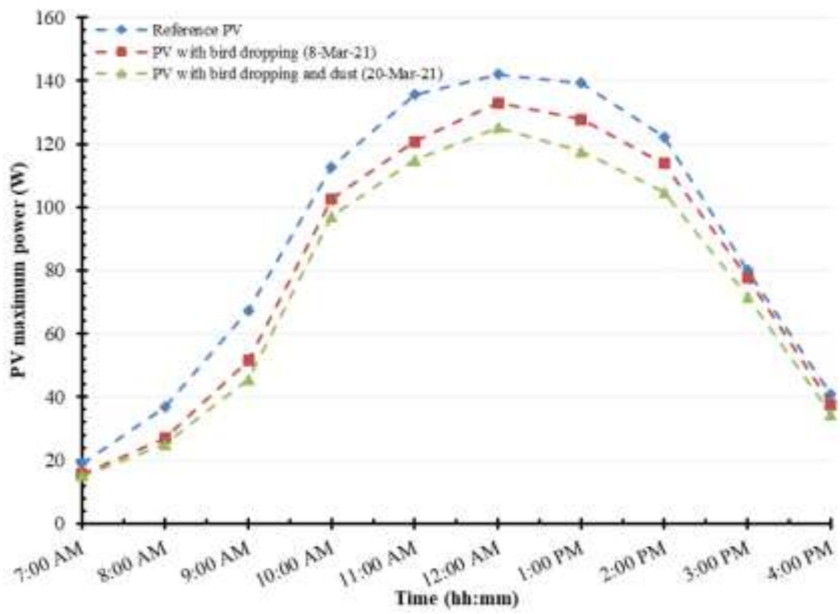

Figure 7. The impact of bird droppings on PV module power production.

As seen in Figure 7, the reduction in the output power at noon equals 7.4%. That means these droppings affected the PV panel efficiency. This phenomenon shows that this dropping affects the efficiency of the PV panel. There is no similar published data about the effect of bird droppings to compare the results with this study.

RESULTS OF SHADING EFFECT

As seen in the figures below, the influence of quarter and half shading on the current (I_{sc}), voltage (V_{oc}), and output power (P_{max}) of PV modules.

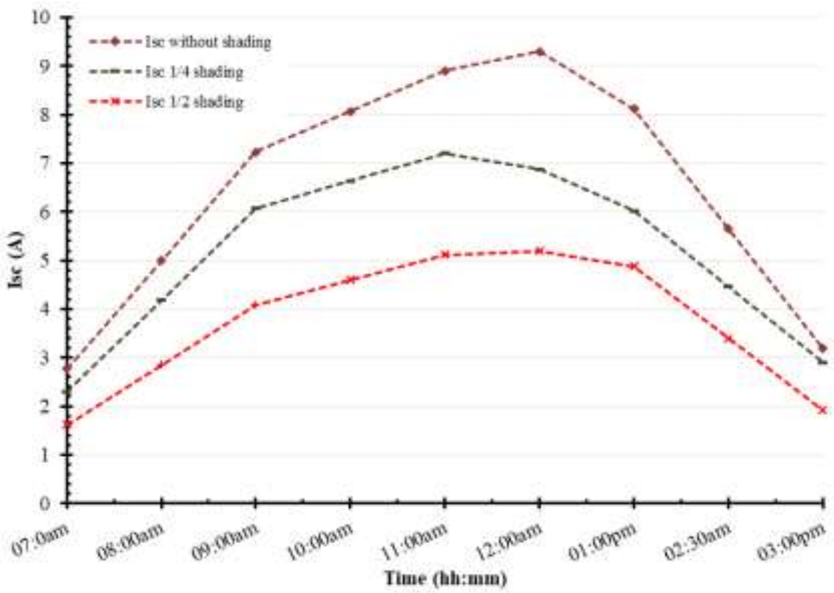

Figure 8. Effect of shading on the short circuit current (I_{sc}).

Figure 8 shows that the short circuit (I_{sc}) for quarter shading decreases with percentage (19.1%). At half shading, the short circuit current (I_{sc}) reduced by (42.5%) comparing with the current without shading. The effect of shading on the open circuit voltage (V_{oc}) can be observed in Figure 9.

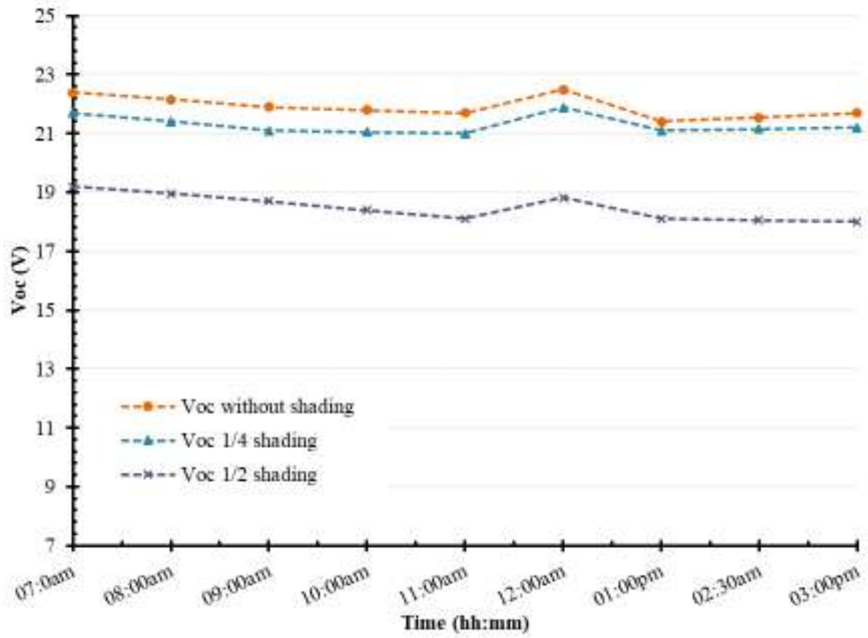

Figure 9. Effect of shading on the open circuit voltage (V_{oc}).

The obtained results in Figure 9 indicated that the open circuit voltage (V_{oc}) decreases with shading. The value of the reference PV module (without any shaded effect) at noon is 22.6 V, but when the covered quarter area of the PV panel, the voltage (V_{oc}) decreased by up to (3.2%). When the covered area was increased to half, the reduction in (V_{oc}) was increased to a (16.6%). These reductions in I_{sc} and V_{oc} have dramatically influenced the maximum power output of the PV module. As shown in Figure 10.

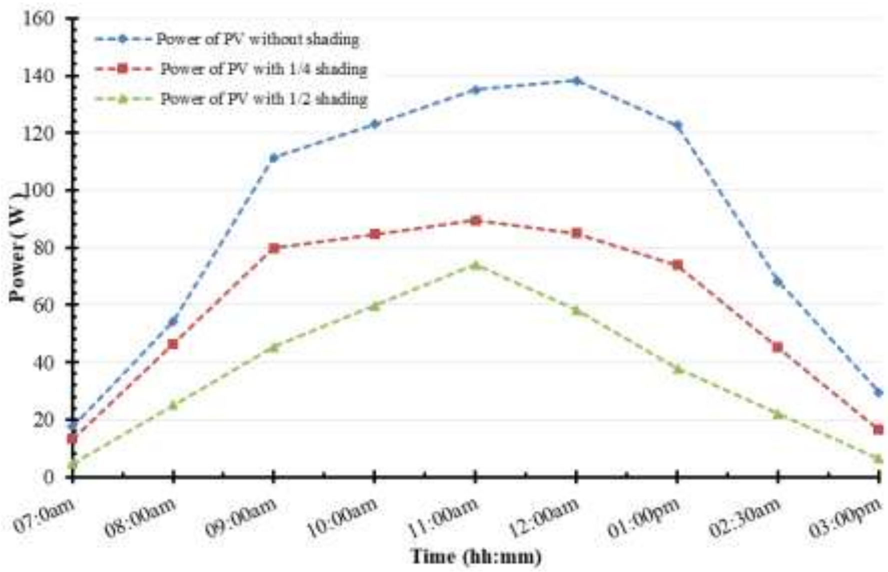

Figure 10. The effect of shading on the output power of the PV panel.

The output power reduced dramatically with increasing the area of shading on the PV module surface. For quarter shading, the amount of power reduction is (33.7%). With half shading, the percentage increases to (45.1%). At three-quarters shading, the amount of power is very low, and the reduction was equal (92.6%). The published data in the literature survey makes it impossible to compare such results because all the published literature survey does not mention the partial shading on the PV module.

CONCLUSION

The research presented four emerging sustainable practices Photovoltaic (PV) has been outdoor tested to analyze and investigate the environmental factors that interfere with the PV module. Three experimental are done; dust accumulation, Birds droppings (fouling), and shading effects were constructed and tested experimentally on a building's roof in Jeddah, Saudi Arabia, in March and Abril 2021. A method for estimating the reduction in the energy output of a PV module due to dust on its surface was introduced in the study. The procedure is based on using a clean comparison panel and a panel with particles of dust deposition on the floor. Experiments were conducted on the power of solar photovoltaic panels exposed to environmental dust. Dust's impact on PV panel power and efficiency as well reduction as was calculated. The results indicate that dust has a significant effect on power generation by 12.2% and also the reduction in efficiency by 11.86%. The shading effects of cells significantly impact the quality of the power produced by the photovoltaic panel. The energy yield of a photovoltaic device that is partially shaded is much smaller than that predicted by the mean solar irradiance. The results above show the percentages of reductions of current (I_{sc}), voltage (V_{oc}), and power ($P_{o/p}$). The percentage of reduction increases with a decrease in the area of PV modules that received the sunlight, with quarter shading, the reductions in I_{sc}, $V_{oc,}$ and power are 19.1%, 3.2%, and 33.7%, sequentially. At the same time, the reductions of half shading are 42.5%, 16.6%, and 45.1%, sequentially.

REFERENCES

[1] F. Alrasheda, and M. Asif, "Climatic classifications of Saudi Arabia for building energy modelling", Energy Procedia, Vol. 75, Pp. 1425 – 1430, 2015. doi: 10.1016/j.egypro.2015.07.245.

[2] E.S. Hrayshat, "Visibility of solar photovoltaics as an electricity generation source for Jordan", Renewable Energy, Vol. 34, No. 10, Pp. 2133-2140, 2009. https://doi.org/10.1016/j.renene.2009.03.006.

[3] National Renewable Energy Program. https://ksa-climate.com/making-a-difference/nrep/. (accessed on 1 March, 2021.

[4] M.R. Gomaa, W. Hammad, M. Al-Dhaifallah, and H. Rezk, "Performance enhancement of grid-tied PV system through new design cooling techniques under dry desert condition: an experimental study and comparative analysis", Solar Energy, Vol. 211, Pp. 1110–1127, 2020. https://doi.org/10.1016/j.solener.2020.10.062.

[5] M.R. Gomaa, M.A. Mohamed, H. Rezk, M. Al-Dhaifallah, and M.J. Al shammri, "Energy Performance Analysis of On-Grid Solar Photovoltaic System- a Practical Case Study", International Journal of Renewable Energy Research (IJRER), Vol. 9, No. 3, Pp. 1292-1301, 2019.

[6] R.J. Mustafa, M.R. Gomaa, and H. Rezk, "Environmental Impacts on the Performance of Solar Photovoltaic Systems", Sustainability, Vol. 12, 2, Pp. 608, 2020. https://doi.org/10.3390/su12020608.

[7] L.M. Ayompe, A. Duffy, S.J. McCormack, and M. Conlon, "Validated Real-time Energy Models for Small-Scale Grid-Connected PV-Systems", Energy, Vol. 35, No. 10, Pp. 4086-4091, 2010.

[8] C. Breyer, A. Gerlach, O. Beckel, and J. Schmid, "Value of solar PV electricity in MENA region", Energy Conference and Exhibition (EnergyCon), 2010 IEEE International. doi: 10.1109/ENERGYCON.2010.5771744

[9] Solar GIS. SolarGIS data validation for the Kingdom of Saudi Arabia, http://geomodelsolar.eu/_docs/various/SolarGIS_validation_SaudiArabia_2013-02.pdf.

[10] S.A.M. Said, M.A. Habib, and M.O. Iqbal, "Database for building energy prediction in Saudi Arabia", Energy Conversion and Management, Vol. 44, Pp. 191–201, 2003.

[11] M.M.A. Khan, M. Asif, and E. Stach, "Rooftop PV Potential in the Residential Sector of the Kingdom of Saudi Arabia", Buildings, Vol. 7, No. 46, 2017. doi:10.3390/buildings7020046

[12] Planning and installing photovoltaic systems, "A guide for installers, architects and engineers", Deutsche Gesellschaft für sonnenenergie (DGS LV Berlin BRB), 2008.

[13] E.E. Van Dyk, E.L. Meyer, F.J. Vors ter, and A.W.R. Lei tch, "Long-term monitoring of photovoltaic devices", Renewable Energy, Vol. 22, Pp.183-197, 2002.

[14] https://www.seaward.com/gb/support/solar/faqs/00797-how-does-temperature-and-irradiance-affect-i-v-curves/ (accessed on 25 March 2021).

[15] C. Xiao, X. Yu, D. Yang, and D. Que, "Impact of solar irradiance intensity and temperature on the performance of compensated crystalline silicon solar cells", Solar Energy Materials & Solar Cells, Vol. 128, Pp. 427–434, 2014. http://dx.doi.org/10.1016/j.solmat.2014.06.018

[16] H. Rezka, M. AL-Oran, M.R. Gomaa, M.A. Tolba, A. Fathy, M.A. Abdelkareemh, A.G. Olabih, A.H.M. El-Sayed, "A novel statistical performance evaluation of most modern optimization-based global MPPT techniques for partially shaded PV system", Renewable and Sustainable Energy Reviews, No. 115, Pp. 109372, 2019. https://doi.org/10.1016/j.rser.2019.109372.

[17] Electropaedia, Solar Power (Technology and Economics), Woodbank Communications Ltd, 2021. http://www.mpoweruk.com/solar_power.html. (accessed on 25 February 2021)

[18] M.R. Gomaa, M. Al-Dhaifallah, A. Alahmer, and H. Rezk, "Design, Modeling and Experimental Investigation of Active Water Cooling Concentrating Photovoltaic System", Sustainability, Vol. 12, No. 13, Pp. 5392, 2020. https://doi.org/10.3390/su12135392.

[19] M.R. Gomaa, R.J. Mustafa, and H. Rezk, "An Experimental Implementation and Testing of a Concentrated Hybrid Photovoltaic/Thermal System with Monocrystalline Solar Cells Using Linear Fresnel Reflected Mirrors", International Journal of Energy Research, Vol. 43, Pp. 8660–8673, 2019. https://doi.org/10.1002/er.4862

[20] A. Ndiaye, C.M.F. Kébé, P.A. Ndiaye, A. Charki, A. Kobi and V. Sambou, "Impact of dust on the photovoltaic (PV) modules characteristics after an exposition year in Sahelian environment: The case of Senegal", International Journal of Physical Sciences, Vol. 8, No. 21, 2013.

[21] H. Rezk, Z.M. Ali, O. Abdalla, O. Younis, M.R. Gomaa, and M. Hashim, "Hybrid moth-flame optimization algorithm and incremental conductance for tracking maximum power of solar PV/thermoelectric system under different conditions", Mathematics, Vol. 7, Pp. 875, 2019. https://doi:10.3390/math7100875

[22] H. Rezka, M.R. Gomaa, M.M. Marmoush, N. Shehata, and J. Henry, "Theoretical and experimental performance investigation of a newly combined TDD and SWH system", Applied Thermal Engineering, Vol. 161, Pp. 114156, 2019. https://doi.org/10.1016/j.applthermaleng.2019.114156.

[23] M.M. Marmoush, H. Rezk, N. Shehata, J. Henry, and M.R. Gomaa, "A novel merging Tubular Daylight Device with Solar Water Heater-Experimental study", Renewable Energy, 125, Pp. 947-961, 2018. https://doi.org/10.1016/j.renene.2018.03.031.

[24] R. Hosseini, N. Hosseini, and H. Khorasanizadeh, "An experimental study of combining a photovoltaic system with a heating system", World Renewable Energy Congress (at: Linkoping, Sweden 2011). 8-13 May. doi: 10.3384/ecp110572993.

[25] S. Ghazi, and K. Ip, "The effect of weather conditions on the efficiency of PV panels in the southeast of UK", Renewable Energy, Vol. 69, Pp. 50-59, 2014.

[26] B. Yerli, M.K. Kaymak, E. İzgi, A. Öztopal, and A.D. Şahin, "Effect of Derating Factors on Photovoltaics under Climatic Conditions of Istanbul", International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering, Vol. 4, No. 8, 2010.