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Research Article

Performances of Photovoltaic Modules Function in an Aggressive Environment, Experimental Study

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Abstract

The electrical performances of photovoltaic panels can change depending on several factors some of which are: irradiance, temperature, humidity and accumulation of dust, these factors can significantly reduce the efficiency of the panel. In order to prevent this from happening we need to track the behavior of the solar panel using the I-V and P-V characteristics under an indoor test bench. In this paper, we investigated the electrical performances of a crystalline silicon C-Si PV module under several aggressive environmental factors, where we chose a range of 33.3 to 74.3 ° C for the study of temperature and we have also studied the effect of hot spot phenomena produced by partial shading as well as the circulation of water on the surface of the solar panel.

Keywords: Solar panel, temperature, irradiations, efficiency, dust

1. Introduction

With the drastic fall in oil prices and its effect on the international economy, finding an energetic alternative is a crucial objective for many governments. Today the renewable energy sector provides us with multiples alternatives such as: wind, hydro, solar, geothermal and bio-energy sector [1].

The solar energy sector is the best known and the most used since it is the most abundant source of energy on the planet and it is the fastest in term of generating electrical power [2]. Compared to the other renewable energies solar energy is much less location independent than hydro and wind energy, it is of less cost and risk compared to tidal and geothermal energy, and more simple compared to wind and waves energies. Moreover, solar technologies are always advancing and becoming more efficient and require no moving parts it makes no noise and produces zero emissions. Another important advantage of solar energy is that it allows customers to take control on their electricity production by installing photovoltaic panels on their roofs, as they can operate for years without much operating and maintenance costs [3 ; 4].

The Algerian economy depended on oil sales during past half a century but today and especially after the collapse of world oil prices in the beginning of the first six of 2014, the country search for other clean and proper energies to contribute in her economy [5]. Due to its large area (2.381 741 Km2), Algeria has a high potential of solar energy particularly in the Saharan region that accounts approximately 86% of its area [5; 6]. The country benefits from around 3000 hours of sunshine per year, which gives it the largest solar field in the world and the largest capacity in the Mediterranean basin. By exploiting it, Algeria would be able to produce more than 169,400 terawatts per hour, that's 5000 times the annual national consumption of electricity [6]. For now Algeria has a plan to reach an annual capacity of 200 MWp over the 2021-2030 periods and to achieve by 2030 more than 37% of national electricity production. In this aim it has installed more than 22 solar power plants across the country. The plant in Djelfa, is the largest in terms of production capacity, with 190,000 solar panels with a building cost of more than 11 Billion Algerian dinars (US$93 million) [6].

Photovoltaic panels dominate the solar market, they are the main source of electricity in solar power plants because of their simplicity of installation and operation; they are of rapid technological development this expansion of the market leads to very low prices and they have a life cycle of around 25 years [7]. Photovoltaic panels are generally made of silicon in 95% of global installations [8], and are built under standard test conditions corresponding to a temperature of 25 ° C and a radiation of 1000 W / m2, which are not the actual conditions of the environment in which the panels are installed and called upon to operate [9].

PV panels can be installed in aggressive environments, where they are exposed to external weather conditions which will certainly affect their performance such as very high temperature levels in the desert area. For example, in a study carried out in a region of the Algerian Sahara, it is mentioned that the temperature at this site was between 40 ° C and 63 ° C with an annual average of daily global irradiations of around 7 KW /m2 [10]. In addition to the frequent sandstorms in these regions which cause a lot of soiling on the surface of the panels. On the other hand, the Sahelian regions (Seaside) can also affect the efficiency of

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photovoltaic panels due to the high humidity amounts of these areas.

The efficiency of a PV panel is directly linked to its physical properties which are represented by the voltage and the current intensity [11]. Thus to study the efficiency of a photovoltaic panel, it is necessary to study its performances via current-voltage (I-V) and power-voltage (P-V) characteristics under the effect of different factors. To this end, we have studied in this article the effect of irradiance, dust accumulation, temperature, titer angle and scratched glass on the performances of a C-Si solar panel (20×15 cm) using a 500W light source.

2. The effect of environmental aggressive factors on Photovoltaics panels performances

In this section we will describe the effect of the most important environmental factors on PV panel's performances.

2.1 Temperature

The efficiency of photovoltaic (PV) modules is strongly affected by the temperature of their cells [8]. During its installation in different climates and different sites, several parameters can influence the increase of the latter; the ambient temperature in the sites of the Saharan regions, the dirtiness on the surface of the PV module, the partial shading of the PV module, as well as other parameters relate to the solar irradiation and its reflection and absorption by the semiconductor material which represents the solar cell.

The increase in temperature involves several modes of failure or degradation of the PV modules because if a small part of the solar radiation is converted into electricity, most of it is converted into heat (85%), which reduces the efficiency of the photovoltaic module [9; 10]. High temperatures increase the stresses associated with thermal expansion and also increase the degradation rates. From an electrical point of view, increasing the temperature reduces the output power of the PV module.

2.2 Dust

Dust can be defined as tiny crushed particles of less than 500 µm, from various sources such as construction sites, industries and dust storms [11].

The accumulation of dust on the surface of the PV module creates a shade which reproduces the effect of diffused light once the repartition is uniform and several shadow points called hot spot once the repartition of dust is random, both phenomena causes the PV panel to overheat due to reflection or absorption of a portion of the incident solar radiation by the dust layer which causes a significant decrease in the output power of the PV modules [12; 13].

2.3 Irradiation

Solar radiation has a direct effect on the cells temperature because this temperature increases with increasing solar radiation. The increase in solar radiation increases the output current until the temperature of the cell interferes and causes it to drop. Low current and low voltages decrease the resulting power and efficiency of the cell [14]. Another effect of solar radiation is that it causes discoloration of the encapsulate which is a common type of degradation in photovoltaic (PV) modules, which greatly affects its performance. This phenomenon is attributed to a decrease in the fill factor by non-uniform discoloration and an increase in series resistance of cell contacts, and to some extent to its direct light reducing effect [15]. Discoloration of PV modules can be identified by a visual inspection where it is clearly visible that the module changes color to yellow [16].

2.4 Scratched glass

Solar glass is imprtant for improving the efficiency of PV modules, maximum optical transmission through the protective glass is necessary for the life of the cell and it is an essential part of solar panels protecting the solar cells while providing high solar radiation to the substrate. However, it is exposed to the cleaning of mechanical contacts and to the impact of sand particles when operating in outdoor environments, resulting in loss of optical efficiency as well as a decrease in mechanical integrity, durability and can also lead to early loss optical transmission by local deformation, scratches and cracks. Other factors influencing the mechanical properties of glass are its chemical composition and processing techniques. As a result to these factors, it is possible to manufacture glass with unique advantageous characteristics necessary for specific applications [17].

2.5 Sand storms

In the desert regions, sandstorms and accumulation of dust are major environmental factors that can affect the amount of solar radiation received by surfaces of photovoltaic panels in two ways, firstly by increasing the amount of accumulated dust on the surface of the PV panels because in times of sandstorms, the particle deposition density is much higher and on the other hand by making the atmosphere around the PV panels opaque with the heavy presence of dust particles. This accumulation of dust decreases the transmittance of the PV panel resulting in reduced energy and power production. The deposited dust has more detrimental effects on small tilt angles, and is not easily washed away by the rain. It can also scratch the glass of the module which also results in degradation of the performance of the panel [18, 19].

2.6 Snow

High latitude PV systems are subject to snow cover as well as less solar exposure Snow cover reduces the amount of solar irradiance reaching the PV cells, resulting in a partial or total reduction in electricity production depending on the amount of snow on the panel surface. Losses due to snowfall also depend on the angle of inclination of the photovoltaic panel and the technology considered. Overall, it has been found that proper assessment of snow loss can help improve system performance and maintenance [20, 21, 22].

2.7 Humidity

Moisture penetrating the PV module through the laminated edges causes corrosion that attacks the metal connections of the PV module cells, resulting in increased leakage currents and thus loss of performance. It also degrades the adhesion between the cells and the metal frame [23]. In addition, water vapor droplets suspended in the atmosphere, can disperse, refract or diffract incident sunlight. Wet conditions can therefore reduce the power produced by the PV module. However, increased efficiency of PV panels is observed at low relative humidity [10] because the deposition of the water on the front side of the PV panel improves absorption of the solar spectrum by the solar cell of PV module; the presence of the water on the front side creates a thin layer of water, this layer improves the optics properties of the solar panel through the adaptation of the index between the refraction index of the area and the refraction index of the PV module glass.

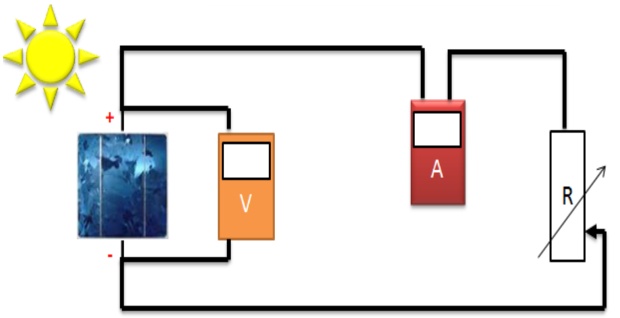
It is noted here that the presence of several environmental parameters together implies the presence of other types of distrust on the PV module and the degradation of these electrical performances, such as for example the TID (Temperature Induced Degradation) phenomenon which results from the rise in temperature and the sunshine and which leads to a power of 15% on polycrystalline photovoltaic modules or PID (Potential Induced Degradation) which attacks the PV module installed in a humid environment [24].

3 Methods

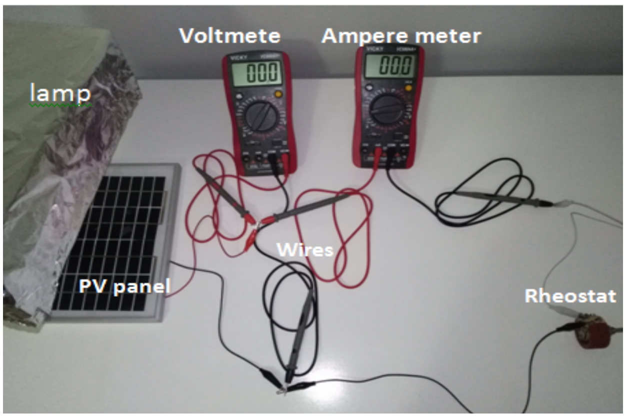
3.1 Experimental test bench

This part deals with the electrical characterization of PV module performances under different operating conditions (temperature, irradiation, dust...). The analysis of the behavior of the PV module in these conditions passes by the analysis of the I-V and P-V curves, for that we carried out the interior test bench (Synoptic diagram and experimental setup) presented on the bellow, figure (1-a-b), it consists of:

- Light source lamp of 500 Watt.
- Voltmeter for measuring the voltage at the terminal of the PV module
- Ammeter for current measurement by the PV module.
- Rheostat for creates a variable load.
- Small solar panel in C-Si with 5Watt power pick.
- Electrical wires for connections.



(a)



(b)

Fig.1. Test bench for the electrical characterization the PV module; a) synoptic diagram, b) Experimental test bench setup.

The electrics parameters of the solar panel used are shown in the following table:

Table1. Photovoltaic module characteristics.

Parameters	**Characteristics**
Panel type	Monocrystalline
Power pick (Watt)	5
I_{sc}(A)	0.32
V_{oc} (Volt)	21.6
I_{max} (A)	0.29
V_{max} (Volt)	17.5
Dimensions L x W x D (mm):	250 ×185 ×18

For the test bench used to study the entire experiments of the effect of the aggressive environment on the performance of the PV panel, Figure (2) present the test bench setup where we test the effect of all the parameters; irradiance, temperature, dust, tilt angle, effect of the scratched glass, hot spot and the effect of the water circulation on the performances of the PV module. The test bench is composed with the electrical test bench presented in the Figure 1 in addition with the PV solar panel under one effect of the aggressive parameters previously mentioned.

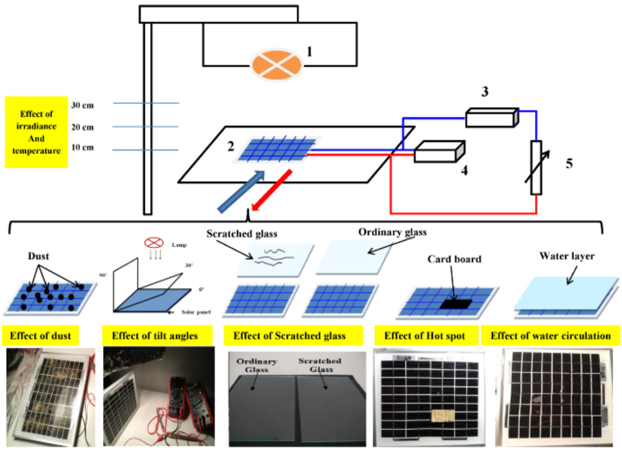


Fig. 2 Synoptic diagram of the test bench used to study the entire experiment of the effect of the aggressive environment on the performance of the PV panel; 1) Light source lamp of 500 Watt, 2) Solar panel, 3) Ammeter, 4) Voltmeter, 5) Rheostat.

3.2 The aggressive environment parameters to be studied

This section describes the methodology followed to the test and the experimentation of the aggressive environment parameters on the PV panels.

3.2.1 The effect of irradiance and temperature

For the study of the effect of the variation of the irradiation levels on the electrical PV performances; we have carried out the assembly shown in the block diagram Fig (2), the position of the lamp is modified for the following three levels: 10, 20 and 30 cm between the lamp and the solar panel, the variation of lamp position implies the variation of the irradiation level according the inverse square law [25]. In the other hand, for the study of the effect of temperature on the PV module, which is considered as one of the main aggressive environmental parameter that affect the performance of the PV module, in this study, the photovoltaic module is heated by the lamp used for lighting, the distance between the lamp and the PV module is fixed to 30 cm and the performance of the PV module is calculated under different working temperatures.

3.2.2 The effect of dust

For the experimentation of the effect of dust on the performance of the PV module, the experimental part of this test takes place in four essential steps illustrated in Figure (3). First, a sieve is used. This tool allows us to sort the dust particles according to their diameter. The sieve used has openings varying between 0.05mm and 5.6mm. In our experience, we have chosen to work with dust that comes from the ground, with a diameter of 0.25mm. After this step, we move on to the deposition of dust on the surface of the PV module. In order to have an even distribution of dust over the entire surface of the PV module, an air compressor is used to blow air over the PV module. A distance of two meters is respected between the compressor and the PV module during the blowing of dust on the PV module. To know the density of the dust deposited on the PV module, a piece of glass measuring 10cm × 10cm is used as a witness. A digital scale is used to weigh the piece of glass with and without its dust. After these steps, the PV module is sent for electrical characterization. We note here that the distance between the lamp and the PV module is maintained at 30 cm. The electrical performance of the PV module is studied under three levels of dust density: 1gr, 3gr and 5gr.

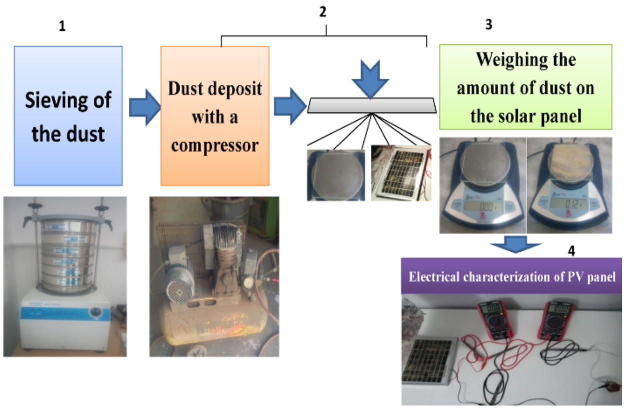


Fig. 3 Experimental test bench for the study of the dust accumulation effect on the PV module.

3.2.3 The effect of tilt angles and scratched glass

The tilt angle is considered as the direct result of the effect of the wind on the solar panel or an incorrect orientation of the PV module. In this paper, we study the variation of the tilt angle of the PV module under the three cases 0 °, 30 ° and 90 °, the distance between the lamp and the solar cell is fixed at 30 cm. the test bench used in this experiment is illustrated in Figure 2.

For the study of the effect of the scratched glass which is considered as the results of aggressive environment like sandstorms, hail; or the result of the cleaning of the PV module with a brush. In this experiment we use two glass samples of the same size and characteristics deposed on the front side of the PV panel, the first one is an ordinary glass (not scratched glass), the second one is a scratched glass, the electrical performances of the PV module is tested with the two glasses types.

3.2.4 The effect of Hot spot effect and water circulation

The Hot spot phenomena can be defined as the results of partial shade or a partial deposition of dust on the solar panel, in order to study the effect of the hot spot on the performance of the PV panel; we have covered part of PV module with a card baord, as shown in Figure (2).

On the other hand, for the study of the effect of the water circulation on the front side of the PV panel or on the air. The presence of water on the PV panel can be considered as an aggressive environmental factor represented by the high level of the humidity near the installation of the solar panel, also, water can be used as a liquid to cool the panel against the high level of temperature or can be used to clean the panel against the deposit of dust, thus, this section is presented as a solution against aggressive environmental factors just as, high level of temperature, dust accumulation and hot spot phenomena present by no-uniform deposition of the dust, furthermore , this section can be presented as the positive effect of the high level of humidity in the air.

For this experiment, a 20ml of water are deposed on the surface of the PV module, a comparison between the performance of the PV panel with and without presence of the water on the surface of the PV module are done.

4. Results and discussion

4.1 The effect of irradiance and temperature:

After the exposition of the solar panel to the three radiations levels of the lamp, the obtained results are present in Figure (4); it shows that the power of the PV module varies in proportion to the variation of the irradiation. The results obtained show that the short circuit current is the electrical parameter most affected by the variation in solar irradiation compared to the open voltage.

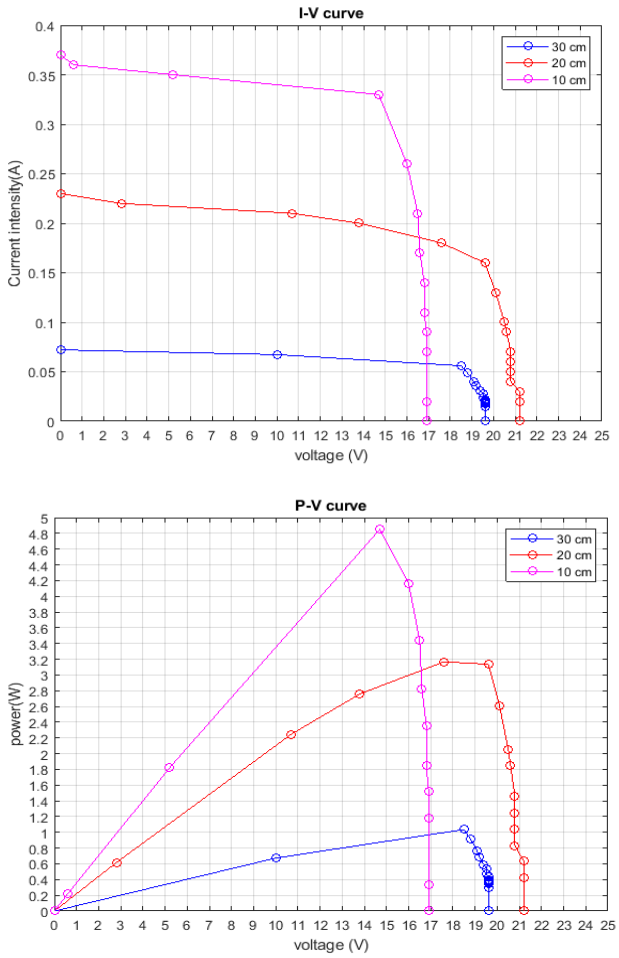


Fig.4 Experimental results of the effect of irradiance on the I-V and characteristic.

For the effect of temperature, Table 2 and figure 5 shows the results obtained at the different test points varied from 33.3°C to 74.3°C.

From the results obtained Fig (5), it can be seen that the increase in temperature affects the power of the PV module; the origin of this degradation is the open circuit voltage, this last (V_{oc}) varies as a function of the gap energy of the semiconductor material according to the Varshni relation [26]:

$$V_{OC} = \frac{E_g}{q} - \frac{KT}{q}\left(\frac{j_{sc}}{j_{00}}\right) \quad (1)$$

$$E_G\,(eV) = Eg_0 - \alpha\, T^2/(T+\beta) \quad (2)$$

$$Pout\ = V_{os} * J_{sc} * FF \quad (3)$$

Table 2 Experimental results of the effect of temperature on the PV module.

T(°C)	I_{sc} (A)	V_{oc} (Volt)	Pout (Watt)
33.3	0.1	16.3	1.63
38.3	0.1	15.9	1.59
42	0.1	15.1	1.51
43.5	0.1	14.6	1.46
52	0.1	12.7	1.27
63.4	0.1	10.7	1.07
67.8	0.1	8.5	0.85
71.2	0.1	5.4	0.54
74.3	0.1	4.2	0.42

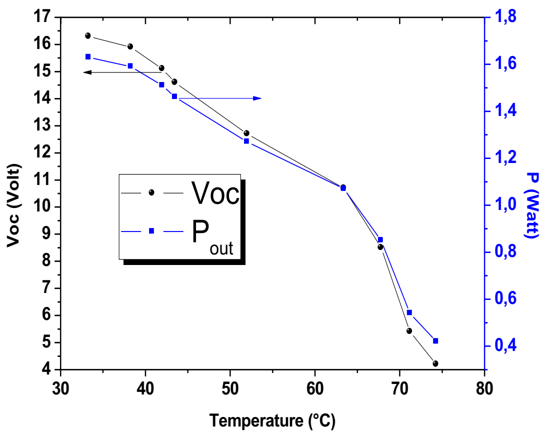


Fig. 5 The effect of temperature on the open circuit voltage and maximum power of the PV module.

Where: T: is the absolute temperature in Kelvin, β and α are two constants given by Table 3, E_{g0}: is the band prohibited at T = 0 ° K, j_{00} is a saturation current density pre-factor. *FF*: is the fill factor of the PV panel, Jsc : short circuit current.

Table 3. Thermal Parameters of Silicon semiconductor [26]

Material	Eg(0) (eV)	α_E (eV/K)	β_E (K)
Si	1.170	4.73E-4	636

The power of the PV module decreases by 1.21 Watt for a temperature variation of 33.3 ° C to 74.3 ° C that is to say a degradation of about 74.23%.

4.2 The effect of dust

Figure (6) shows the obtained results of the dusty PV panel with 1gr, 2gr and 3gr of dust density. It is observed from the figure (6) that the accumulation of the dust on the PV module implies a degradation of the short-circuit current and the maximum power of the PV module. This result is explained by the decrease of the transmission of the light due to the dust accumulation.

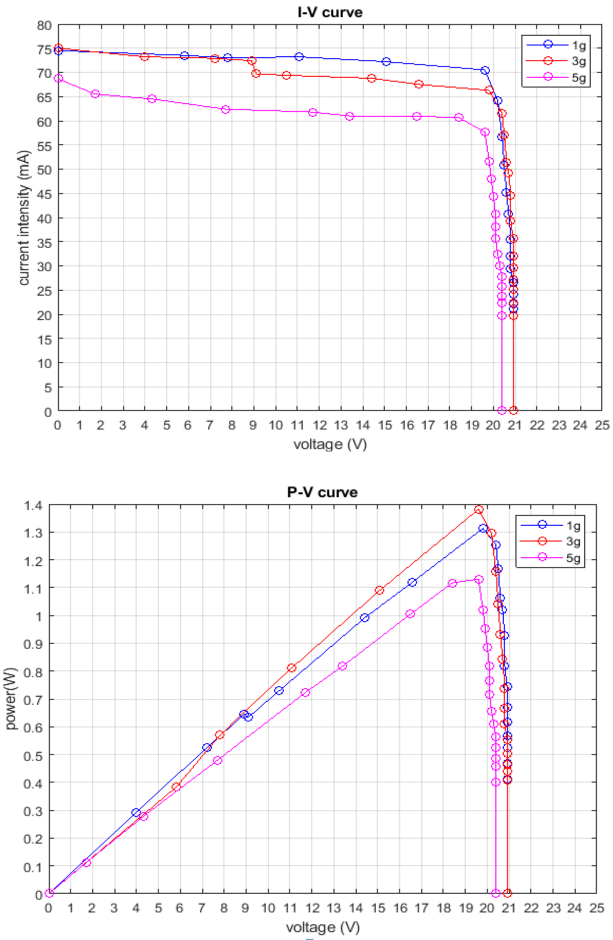
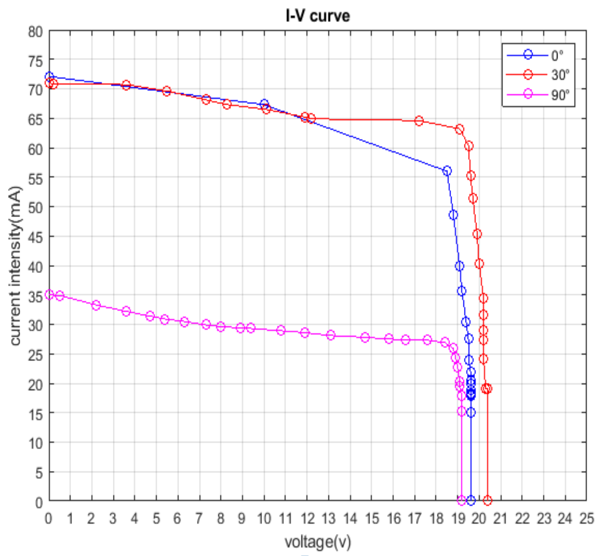


Fig. 6 The effect of dust on the PV module characteristics.



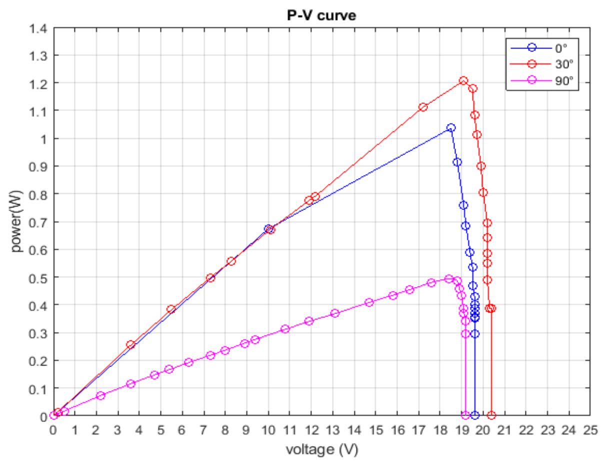


Fig. 7 The effect of the tilt angle of the PV module on its performance.

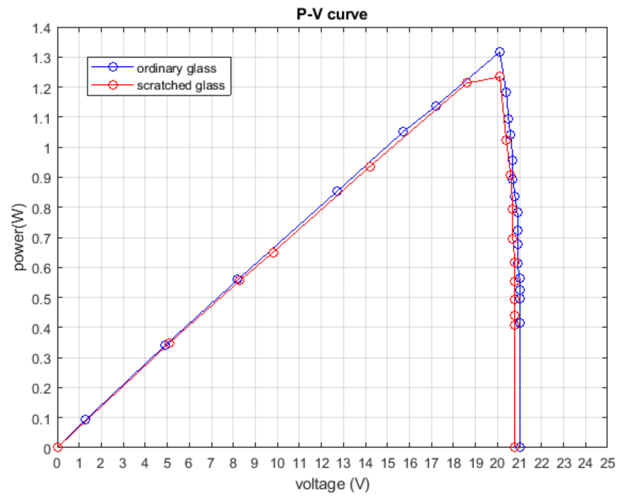


Fig. 8 Experimental results of the effect of scratched glass on the PV module.

4.3. The effect of tilt angles and scratched glass:

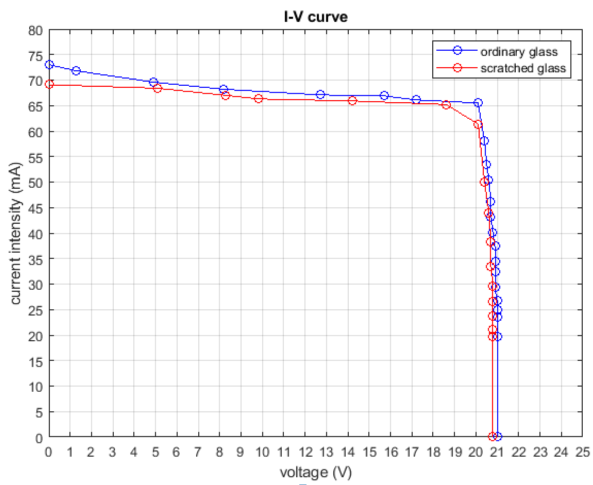
For the effect of the tilt angle on the PV panel, the results obtained show that, with the increase of the tilt angle, the performances of the PV modules decreases fig (7); the best results are obtained with the angle 0 ° which represents a perpendicular irradiation incidence on the PV module.

For the effect of the scratched glass on the electrical performance of the PV module, the I-V and P-V characteristics of the PV module are plotted with the two types of glass (ordinary and scratched glasses). Figure (2) shows the experiment bench for studying the effect of scratched glass on the PV module. The obtained results from this experiment fig (8) show degradation in the electrical performance of the PV module due the scratched glass.

4.4. Effect of Hot spot effect and water circulation:

For the effect of the hot spot phenomena on the PV panel, after exposure of the solar panel to the lamp (PV module covered part with a card bard), the obtained results of the I-V and P-V curves from this experiment are shown in the following figure (9):

The hot spot effect on the electrical characteristics of the solar panel is localized on I-V and P-V curves as a knee, it affects the energy production on the solar panel, we recall here, that the other effect of the hot spot phenomena on the solar panel is the high temperature of the shaded cell compared to the other cells of the PV module, the shaded cell become a receptor of the electric energy, which leads its temperature to increase.



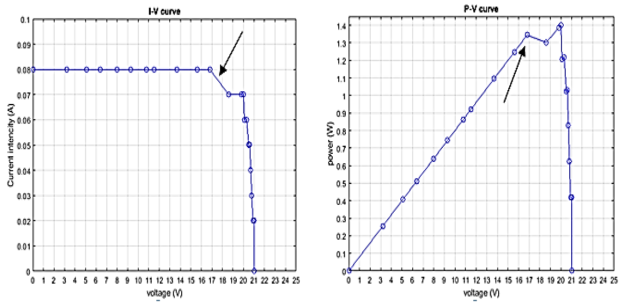


Fig. 9. The effect of hot spot on the PV module.

For the effect of water circulation on the PV panel, after having plotted the panel's characteristics with and without covering the surface of the panel with water, the results are shown in figure (10) below:

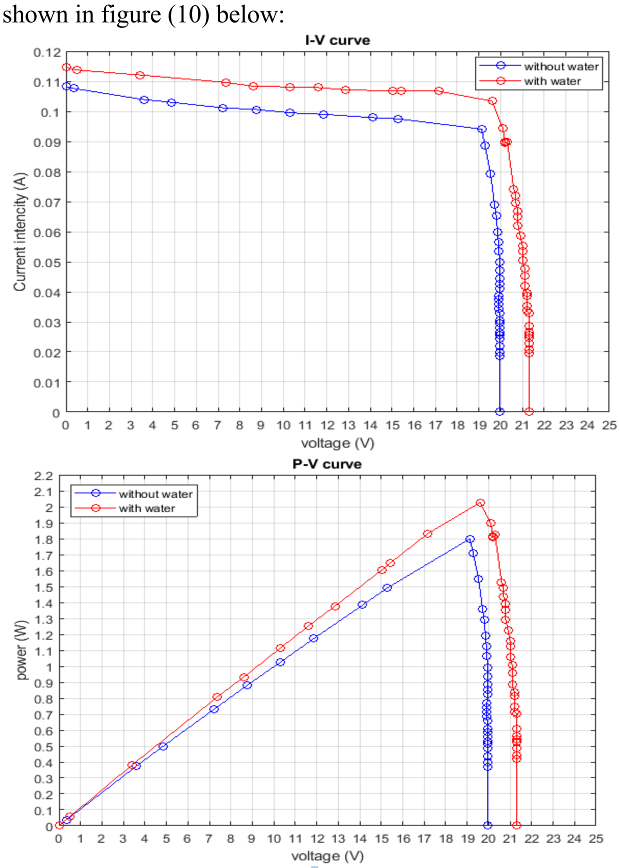


Fig. 10 Effect of water circulation on the front side of PV module.

As the figure shows, the electrical performance of the solar panel has been considerably improved, the maximum power (Pmax) has been increased from 1,799 Watt to 2,026 Watt and the efficiency of the panel has been increased by 12.6%. The improvement in the performance of the PV module is the result of its optical improvement by the adaptation of refractive index between the air (n=1) and the glass (1.52) of the PV module Figure (11), the presence of a layer of water with a refractive index (1.33) between the refraction of air and glass makes it possible to improve absorption of the light spectrum thanks to the phenomena of index adaptation, moreover the presence of water also helps to cool the PV module. These remarks are the interpretation of the improvement of the short circuit current and the improvement of the open circuit voltage of the panel.

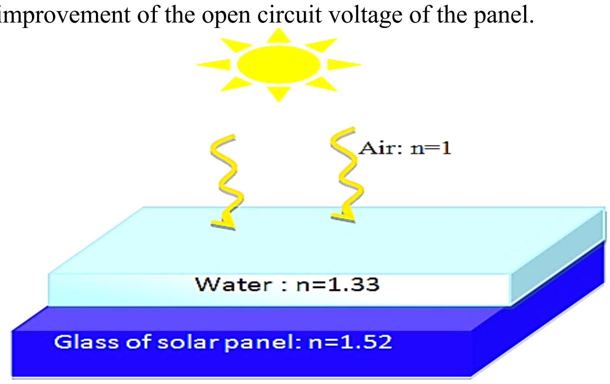


Fig. 11 Effect of water circulation on PV panel: a synoptically presentation of Adaptation of refractive index between air and frond side of PV panel.

5. Conclusion

Photovoltaic panel installations are usually located in aggressive environments that can affect their efficiency and performances, due to several natural factors such as: irradiance, temperature and dust accumulation on the panel surface, as well as other factors such as: tilt angle of the panel and the condition of the front surface of the panel glass. As we have seen in this study, these factors affect the electrical performances of PV modules differently. We can emphasize several points. Firstly, the increase in irradiation implies an improvement in the short-circuit current, whereas the increasing of temperature affects the open-circuit voltage with a slight increase in the short-circuit current. Secondly, the accumulation of dust implies a decrease in both short-circuit current and the open-circuit voltage. Also, dust can cause scratches and hot spot phenomena on the front surface of the PV module. So the accumulation of dust should be avoided whenever is possible. Finally, photovoltaic panels require regular cleaning in order to remain efficient and maintain their good performance. Water circulation represents a good solution to improve solar panel efficiency under outdoor conditions.

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