International Journal of Energetica (IJECA)
https://www.ijeca.info
ISSN: 2543-3717 Volume 8. Issue 1. 2023 *Page 24-30*

Optimal tilt angle for photovoltaic panels in the Algerian region of El-Oued in the spring season: An experimental study

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Abstract – *The tendency to exploit solar energy in the electricity production in Algeria is a priority and a major goal of the Algerian government, and for this reason it seeks to provide all the necessary capabilities to achieve this lofty goal. Photovoltaic electricity is one of the effective technologies for the solar electricity production, but before installing any photovoltaic panel, it is important to determine its optimal tilt angle, and based on this, this study allowed to show the optimal tilt angle of the photovoltaic panels in the Algerian region of El Oued in the spring season, and accordingly, two days (March 21st, 2023, and April 21st, 2023) were chosen to conduct this experimental study. Based on the obtained results, the optimal PV tilt angle for the month of March is 33° and 28° for the month of April. In addition, the greater the amount of solar radiation, the higher the efficiency and productivity of the PV panels, as the highest values for them (6.31 % and 62.17 W, respectively) were recorded on April 21st, 2023. The results of this study will contribute to the correct installation of photovoltaic panels in the Algerian region of El-Oued, especially if the photovoltaic panels are equipped with dual-axis solar tracking systems.*

Keywords*:* Solar electricity production, Photovoltaic panels, Optimal tilt angle, Productivity; Performance.

Received: 20/05/2023 – Revised: 12/06/2023 – Accepted: 20/06/2023

I. Introduction

Currently, the world's main source of energy is fossil fuels (gas, oil, and coal), which is a limited source in nature and subject to depletion, non-renewable, and emits polluting gases to the environment. That is why the search for alternative, clean, sustainable, and renewable sources is a priority for all countries of the world [1], especially Algeria.

The Algerian government encourages the speedy establishment of infrastructure for the exploitation of renewable energy sources, especially solar energy. In order to achieve this lofty goal, which is the exploitation of solar energy in many technological fields, many scientific researches published in indexed scientific journals showed that Algeria receives daily a huge amount of solar radiation, as the insolation duration in Algeria is between 2000 and 3900 hours/year and the average available energy is between 1700 and 2650 kWh/m², i.e. 5 kWh/m² per day in most parts of the national territory [2, 3]. In the literature, many studies have been conducted on applications that allow the renewable energy exploitation in Algeria, as touched on solar distillation in order to provide potable water [4, 5]. It was also found that Said et al. have conducted several experiments on the possibility of using linear Fresnel reflectors as solar water heaters in the Algerian region of Blida [6, 7], and they have reached the possibility of improving the performance of these linear solar

concentrators by dispersing nanoparticles in pure water [8, 9]. In addition, Ghodbane et al. have conducted experimental, numerical, and CFD modeling of solar water heaters using linear Fresnel reflectors [10, 11]. Moreover, a search studied numerically the possibility of using parabolic trough collectors in centers and industrial facilities to heat industrial nano-oils (MXene based silicone oil nanofluids) [12], knowing that nanotechnology is currently experiencing continuous and amazing development, and it is intended for use in many industrial fields [13, 14]. Another search have studied numerically the possibility of using linear Fresnel reflectors in centers and industrial facilities to heat industrial nano-oils (MXene based silicone oil nanofluids) [15]. Also, a research group has proven the possibility of using linear solar concentrators to drive air conditioners by removing the compressor and replacing it with an ejector and a pump [16-18]. Here, parabolic trough collectors or linear Fresnel reflectors can be used, as parabolic trough collectors are more optical and thermal efficient [19-22], but linear Fresnel reflectors are less expensive [23]. Moreover, Linear Fresnel reflectors can be used to produce solar thermal electricity [24, 25], as solar electric stations can be established in Algeria that operate with these linear solar concentrators and their levelized cost of energy is very acceptable compared to fossil electricity [26]. Several studies have conducted a numerical study on solar water disinfection using small linear Fresnel reflectors [27]. Recent work have created a general algorithm aiming to find the optimal layout of photovoltaic panels on irregularly shaped surfaces [28]. In addition, it has been found that Fernández-Rubiera et al. have studied a saw-tooth trough V-cavity for low-concentration photovoltaic systems based on small linear Fresnel reflectors [29]. As noted, there is a lot of research in the literature encouraging a trend towards the exploitation of solar energy in many fields and important technological applications in Algeria.

The main objective of this study is to determine the optimal tilt angle of the photovoltaic panels in Algerian region of El-Oued in the spring, and therefore, practical experiments were conducted on two photovoltaic panels (PV) that have the same technical characteristics. The experimental study was conducted according to the parameters shown in Table 1. When determining the optimal PV tilt angle, all engineers and technicians will be able to correctly install the PV systems (stand-alone PV systems, and grid-connected PV systems) in El-Oued region, and this will enable these PVs to give the greatest productivity and be more effective.

II. Materials and Methods

The experimental work was carried out on two photovoltaic panels with similar technical characteristics. The Algerian region of El-Oued (33.57°, 6.77, and 50) was selected for the study. The experimental steps were as follows:

Acquisition of two photovoltaic panels (RAGGIE type, RG-M165W model) is with a capacity of 165 watts. The technical characteristics of the two photovoltaic panels under study are shown in Figure 1.

Figure 1. Studied photovoltaic panels and their technical characteristics

- Manufacture of metal holders for photovoltaic panels, as these PV holders can move in both directions, vertical (to track the sun's height, and change the tilt PV angle) and horizontal (to track the sun's path from east to west). These manufactured steel supports can hold the photovoltaic panels in both vertical and horizontal positions.
- Acquisition of measuring devices for climatic conditions (Pyranometer PYR 1307 to measure the solar global radiation, Anemometer Meter (AM-4206M) to measure the wind speed, and Anemometer Meter (AM-4206M) to measure the ambient air temperature.
- Acquisition of measuring devices for electrical parameters (Digital Multimeter MX 20 (METRIX-type) to measure the electric current), and Digital Multimeter CT44053 (CROWN-type) to measure the

electrical voltage. To note, the electrical resistance has been fixed at 5 Ω using a variable resistive load of the ECODIME-type.

- Carrying out the desired practical experiments in two days (March 21st, 2023, and April 21st, 2023) of spring.

As mentioned previously, the aim of the study is to determine the optimal PV tilt angle in the Algerian region of El-Oued, and accordingly, each photovoltaic panel has been linked to the electrical measuring devices to form an electrical cycle, and accordingly, a study of two electrical circuits simultaneously under the same climatic conditions has been studied. but under different experimental conditions as shown in Table 1.

- As shown in Figure 2a, the first circuit will be called the "reference electrical circuit (RC)", and it will contain the reference photovoltaic panel (PVr), a digital multimeter MX 20 (METRIX-type), and an ECODIME electrical resistance fixed at 5 Ω, all three of which are connected in series, while the digital multimeter CT44053 (CROWN-type) to measure the electrical voltage will be coupled in parallel with the variable resistive load.
- As shown in Figure 2b, the second circuit will be called the "electrical circuit under variable conditions (ECVC)", and it will contain the photovoltaic panel under variable conditions (PVcv), a digital multimeter MX 20 (METRIX-type), and an ECODIME electrical resistance fixed at 5 Ω, all three of which are connected in series, while the digital multimeter CT44053 (CROWN-type) to measure the electrical voltage will be coupled in parallel with the variable resistive load.

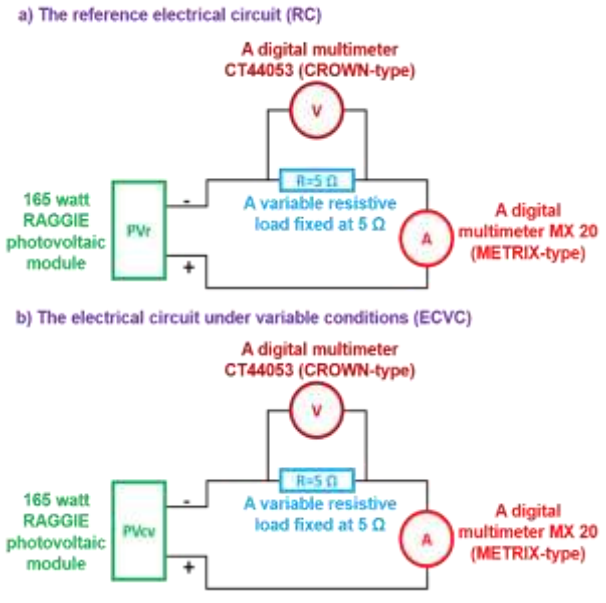

Figure 2. Studied electrical circuits

Table 1 contains the experimental conditions for the two photovoltaic panels, bearing in mind that the two studied photovoltaic panels have been subjected to previous practical experiments under the same climatic conditions and the same experimental conditions to verify their technical and practical similarity. To note, the results of previous experiments have proven a great convergence in the productivity of the two panels under the same experimental conditions, where a small difference in power of ($P = 0.41V \times 0.069A = 0.02869$ watt) was recorded between them. This result ($P = 0.02869$ watt) proved the accuracy of the results obtained, where the productivity of the two photovoltaic panels (PVr and PVcv) is very close under the same operating conditions.

Table 1. Experimental conditions for the study

	PVr			PVcv		
Day	**Tilt angle (°)**	**Tracking system**	**Effective aperture condition**	**Tilt angle (°)**	**Tracking system**	**Effective aperture condition**
03/21/2023	33	Stationary and oriented to the south	Clean	28	Stationary and oriented to the south	Clean
04/21/2023	33	Stationary and oriented to the south	Clean	28	Stationary and oriented to the south	Clean

With regard to the equations used to calculate the output of the photovoltaic panel and its efficiency, they are as follows:

$$P = I \times V \quad (1)$$

$$\eta = \frac{P}{A_{PV} \times I_G} \quad (2)$$

Where, P is the PV output (W), I is the electric current (A), V is the electrical voltage (V), η is the PV efficiency (%), A_{PV} is the effective PV aperture (m²), and I_G is the measured global irradiance (W/m²).

III. Results and Discussion

This study will allow determining the optimal PV tilt angle in the Algerian region of El Oued. As it is known, the performance and productivity of any photovoltaic panel is directly related to changing climatic conditions, and in particular, the amount of global solar radiation that reaches its effective aperture. Figure 3 shows the change in the climatic conditions on the studied days in terms of the change of time from 06h00 to 17h00 (the time when the practical experiments were conducted). From Figure 3, the following can be concluded:

- The global solar radiation for day (April 21st, 2023) is greater than the recorded global solar radiation for day (March 21st, 2023), where the highest value of 1001 W/m² was recorded at 11h00. Through this, it is concluded that the performance and productivity of the photovoltaic panel will be better in the day (April 21st, 2023), and this is what is shown in Figure 4.

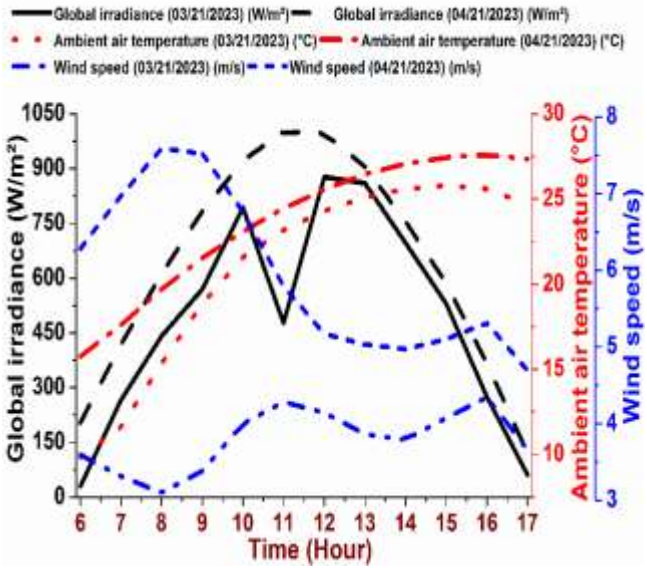

Figure 3. Measured weather data vs. time

- The ambient air temperature for day (April 21st, 2023) is greater than the ambient air temperature for day (March 21st, 2023), as the highest value of 27.6 °C was recorded at 16h00. To note, photovoltaic panels are more productive when ambient air temperatures are moderate or going to low, because high air temperatures reduce the performance and productivity of photovoltaic panels due to voltage drop. Thus, a mild sunny day is the best condition for optimal performance and productivity of the photovoltaic panels.
- The wind speed for day March 21st, 2023) was greater than the wind speed for day (April 21st, 2023), where the highest value of 7.6 m/s was recorded at 08h00.

With the advancement of technology, photovoltaic panels have become more sophisticated and flexible, as they can produce electricity in difficult climatic conditions. Therefore, customers must have a deep understanding of the climatic conditions of the area in which the photovoltaic panels are to be installed, in order to be able to make informed decisions regarding photovoltaic projects.

Figure 4 shows the change in the efficiency and productivity of the two photovoltaic panels (PVr and PVcv). From the curves of Figure 4, it has been observed that:

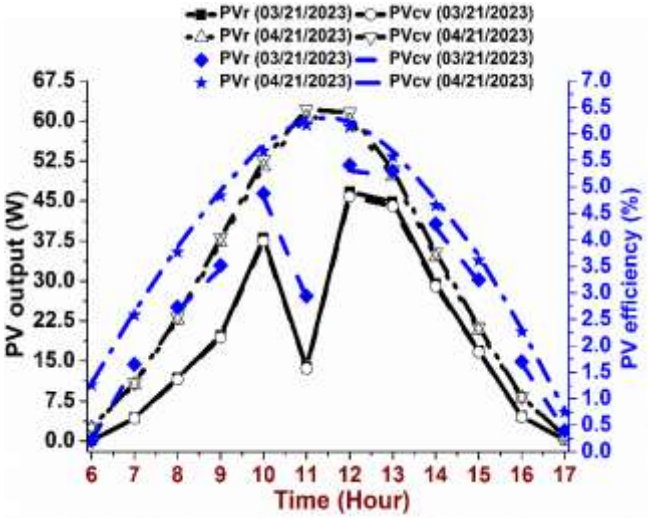

Figure 4. Output and efficiency of the studied photovoltaic panels

- Productivity and performance on day (April 21st, 2023) is better than performance and productivity on day (March 21st, 2023), because day (April 21st, 2023) was full of global solar radiation compared to the other day. It is known that photovoltaic panels will produce the maximum amount of electrical energy when the sun's rays are perpendicular to its effective aperture, and this can only happen throughout the day using sun-tracking systems. If sun-tracking systems are not used, the photovoltaic panels must be directed to the side that ensures that the solar rays fall as long as possible on the photovoltaic panels. In Algeria, the photovoltaic panels must be directed to the south because the sun's path is inclined to the south.

- The optimal PV tilt angle in March is 33°, where the PVr panel gave the best efficiency and the best productivity with values of 5.41% and 46.7 W, respectively, at 12h00.
- The optimal PV tilt angle in March in April is 28°, where the PVcv panel gave the best efficiency and the best productivity with values of 6.31 % and 62.17 W, respectively, at 11h00.

Although the study was conducted in two days in the spring season, the study results proved that in the same season the optimal PV tilt angle in the Algerian region of El-Oued changes from month to month. This change is due to the elliptical path of the earth's rotation around the sun changes its inclination angle as well according to the season. The photovoltaic panels that are installed in the Algerian region of El-Oued have an optimal inclination angle every month, and to know its value accurately, the path of the sun must be tracked daily from sunrise to sunset for a period of one year.

IV. Conclusions

Solar energy can be used to generate electric energy by installing a photovoltaic system that contains photovoltaic cells that convert solar photovoltaic energy directly into electricity. The main objective of this experimental study is to find out the optimal PV tilt angle in the Algerian region of El-Oued in the spring season. The results of the study showed that in the same season, different optimal PV tilt angles can be obtained from month to month. This difference in the optimal PV tilt angle from one month to another is due to the necessity that the effective PV aperture must be completely perpendicular to the solar radiation coming to it, and that the path of the sun changes from one month to another due to the elliptical path of the earth's rotation around the sun.

The most important conclusion of this study is that the optimal PV tilt angle for the month of March is 33° and 28° for the month of April. In addition, the greater the amount of solar radiation, the higher the efficiency and productivity of the PV panels, as the highest values for them (6.31 % and 62.17 W, respectively) were recorded on April 21st, 2023.

The results of this study will contribute to the correct installation of photovoltaic panels in the Algerian region of El-Oued, especially if the photovoltaic panels are equipped with dual-axis solar tracking systems.

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.
- The authors confirmed that the paper was free of plagiarism.

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