Solar Energy 232 (2022) 52–62

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Analytical assessment of Ain Skhouna PV plant performance connected to the grid under a semi-arid climate in Algeria

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ARTICLE INFO

Keywords:
Grid connected Photovoltaic system
Standardized performance analysis
Performance ratio
System efficiency
Semi-arid climate

ABSTRACT

Algeria currently has a number of 24 functional photovoltaic power plants on its national territory, which are poorly investigated. This study focuses on the performance analysis of one of these existing solar power plants. It is located in Ain Skhouna, situated in Saida province, and has a capacity of 30 MWp (polycrystalline solar cell technology). This study was carried out according to the standardized norms IEC 61,724 (IEC) using one year (2018) of data. A linear relationship between the monthly module and ambient temperatures was evaluated (R^2 = 0.994). The monthly total loss increases linearly with the increase in monthly ambient temperature and solar irradiation (R^2 = 0.98). The system efficiency, PV efficiency, and performance ratio are affected by ambient temperature. The average monthly PV, system, inverter efficiencies, and PR were 13.78%, 13.29%, 96.68%, and 85.52, respectively. These results indicate that this PV power plant remains in very good working condition after two years of service.

The effect of climate on PV plant performance was investigated in Algeria by comparing two climates: a semi-arid and a hyper-arid. The results indicate that the semi-arid climate is more favorable than the desert climate for PV power plants for producing electricity and that ambient temperature is a more essential parameter than solar irradiation.

1. Introduction

The main challenge for all countries in the world at the moment is to continuously generate electricity to meet their continuing demand. As a result, the return to renewable energies has become a necessity. It has a variety of advantages, including being a non-polluting and reliable substitute for non-renewable sources. For various reasons as non-pollutant, extensible and sure substitute for non-renewable sources.

As it has fewer ecological consequences and produces less garbage, renewable energy has grown in popularity as an alternative electricity creation resource.

Solar PV is a type of solar renewable energy application that uses the photovoltaic effect to generate electricity. PV systems are classified in a variety of ways based on their design, the efficiency and utility of their supply, and the method in which they are connected to other electrical loads and their interaction with other electrical loads. We can distinguish the connected to the network and the stand-alone systems. Grid-connected PV systems deliver electrical power to the network at the same time as standard energy.Net-connected setups produce electrical energy without battery use or transport (Jaydeep, 2015).

A stand-alone system implicates no interaction with a utility grid; hence, the generated power supplies only the designed load. In the event that the PV array does not directly supply a load, a storage device is needed (Iftakhar et al., 2012), which is generally a battery. When there is a deficit of energy created, the batteries provide it, and when there is an excess of energy produced, they store it. This stand-alone PV power generation will be used to electrify a home or building (Al-Bustam et al., 2012).

Diverse studies have been performed in the literature on PV system performance investigation (Al-Otaibi et al., 2015; Kazem et al., 2014; Attariet al., 2016; Padmavathi et al., 2013; Sundaram et al., 2015; Mensah et al., 2019; Sidi et al., 2016; Wichliński et al., 2018; De Lima et al., 2017; Okello et al., 2015; Daher et al., 2018; Jed et al., 2019; Aoun, 2020). The PV system performance is linked to the type of PV cell used, the inverters and the layout of the installation, and the experimental conditions (solar irradiation, soiling losses, wind speed, ambient

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https://doi.org/10.1016/j.solener.2021.12.055
Received 12 August 2021; Received in revised form 7 December 2021; Accepted 22 December 2021
Available online 29 December 2021
0038-092X/

temperature).

Attari *etal.*, 2016 studied a PV system located on the roof of a government building situated in Tangier (Morocco) for one year (from January 1st, 2015 to December 31st, 2015). The studied grid-connected 5 kWp was composed of 20 solar modules (polycrystalline silicon). The annual capacity factor was 14.84%, and the final yield ranged from 1.96 to 6.42 kWh/kWp. The performance ratio (PR) ranged between 58% and 98%.De Lima et al., 2017 investigated a 2.2 kWp PV system in Brazil (State University of Ceará, Fortaleza) for a year (from June 2013 to May 2014).The reference yield was 5.6 kWh/kWp, the array yield was 4.9 kWh/kWp, and the final yield was 4.6 kWh/kWp. The PR and capacity factor were 82.9% and 19.2%, respectively. The annual system losses were 1.05 kWh/kWp and the annual average array, system, and inverter efficiencies were 13.3%, 12.6% and 94.6%, respectively. In Africa, a 3.2 kWp PV system was installed at NMMU (Nelson Mandela Metropolitan University) and evaluated for one year (2013) (Okello et al., 2015).The PR was 84%. The results of the simulated (PVsyst) and experimental tests were compared. In addition, two simulations employing both measured and simulated (Meteonorm) data were performed. The results showed that the outcomes were identical. When predicting monthly energy yields using measured data, better results were observed. Lena D. Mensah et al., 2019 presented performance research of a PV plant of 2.5 MW situated in Navrongo (Ghana) from June 2013 to May 2016. The annual PR was 70.6% and the capacity factor was 16.2%.In Djibouti, Daher et al., 2018 evaluated the performance of PV plants in desert marine climate conditions. This study was performed for the first 4 years using IEC 61,724 standard. The PV module and system efficiency were 12.68% and 11.75%, respectively. The average PR of the PV plants was 84%.Jed et al., 2019 presented a one-year performance study of a 954.809 kWp PV array at the Sheikh Zayed PV plant in Nouakchott, Mauritania (from September 2014 to August 2015). Insolation and environmental circumstances have an impact on photovoltaic array performance, according to the research. The PR was lower (0.66%), while the capacity factor fluctuated between 20.54% in October and 11.66% in January.

Algeria is particularly interested in photovoltaic solar energy since it has a significant solar resource. Algeria has a year-round insolation of over 2000 h, with 3900 h in the Sahara and highlands. As a result, the national renewable energy potential is dominated by this source. Algeria views this source as an opportunity and a lever for economic and social growth, notably in terms of increasing wealth and employment-generating sectors.

Various PV solar projects with a total capacity of 800 MW have started construction by 2020, while others with a total capacity of 200 MW will be spread between 2021 and 2030. (Web1). A long-term plan has been set as a goal, with 12.000 MW of existing capacity (22.000 MW between 2011 and 2030) covering national demand and another 10.000 MW potentially exportable if long-term purchase guarantees and external funding are secured (Web2). This plan calls for the construction of roughly sixty PV solar and thermal facilities, as well as wind farms and hybrid plants, by 2020. It was carried out under the Ministry of Energy and Mines' supervision.

Currently, there are 23 PV plants in Algeria, which have been established by the SKTM company (Shariket Kahraba wa Taket Moutadjadiada) since 2014. These power plants are classified into three classes based on their geographical location, namely, the East Highlands unit, the West Highlands unit, and the Southern Unit, with capacities of 121.1 MW, 145 MW, and 78 MW, respectively. These photovoltaic power plants were erected as part of a 343 MWp project that was part of the national renewable energy program's first phase (Web3). These power plants were not thoroughly investigated. Indeed, Only one study on the Adrar power plant's performance was found (Aoun, 2020).

This study was carried out to investigate the performance assessment of a 30 MWp PV power plant in Ain Skhouna, located in Saida province (Algeria), for a year (2018), according to the International Electrotechnical Commission standard (IEC 61724).This photovoltaic plant was compared to another in a desert hyper-arid climate, namely Adrar (Algeria), to see how climate affects performance. This paper is divided into three sections. The first is devoted to the system description (the site's geographic location, the PV power station, the performance parameters (standard IEC61724), and the data used), and the second is devoted to the results and discussion. The conclusion was given the last section of the paper.

2. System description

2.1. Geographical location of the site

The Ain Skhouna PV power plant station (30 MWc) is located in Algeria's Saida province (Wilaya), with a latitude of 34°48′43″ north, a longitude of 4°10′58″ east, and an altitude of 900 m (highlands).This location receives a significant amount of solar energy throughout the year, depending on the seasons. Fig. 1 represents the 12-month average daily solar irradiation. It varies by month and season. Winter had the lowest seasonal solar irradiation (G) mean value (124.26 kWh/m^2), and summer had the highest seasonal G mean value (206.28 kWh/m^2). The greatest monthly G value of 224.39 kWh/m^2 was recorded in June, while the lowest monthly G value of 111.04 kWh/m^2 was recorded in January.

The climate in Saïda province is semi-arid, with hot and dry summers and harsh winters with frequent frost. The monthly variation of ambient temperature(T_a), wind speed (v), and relative humidity (Rel.humidity) was illustrated in Fig. 2.The monthly average temperature (T_a) ranges from 9.08 °C in February to 32.99 °C in July, with a mean of 18.48 °C.

The average Rel.humidity is 50%, with the highest value of 63.91% (November) and the lowest value of 22.78% (July). The v varies from month to month, with the highest values recorded in the spring season (8.72 m/s in March) and the lowest values recorded in the winter season (3.42 m/s in December). The v has an average monthly value of 5.68 m/s.

2.2. PV power station description

The Ain Skhouna solar PV plant (Fig. 3) is a grid-connected station; it injects its produced power directly into the national network at 60 kV. It was carried out by the German operators, BELECTRIC group, and Shariket Khahraba wa Taket Mutadjadida (SKTM).This power PV station includes 119.520 polycrystalline silicon PV panels (CS6P-250P type), each one with a peak power of 250 Wp as indicated by its electrical characteristics listed in Table1. These PV panels are oriented towards the south and they are inclined at an angle of 15°.

This power plant has two fields, namely, Saïda 1 (Boucle 1) and Saïda 2 (Boucle 2), with a combined power of 15.936 MWp and 13.944 MWc, respectively. The fields Saïda 1 (Boucle 1) and Saïda 2 (Boucle 2) are composed of eight (08) subfields (named Skide) and seven (07) photovoltaic subfields, respectively. Thus, the Saïda power plant contains a total of 15 subfields. All the subfields are identical, with a peak power of 1.992 MWp each. Two (02) inverters, four (04) central boxes, and a transformer make up each subdomain. Each inverter is powered by two central boxes containing 11 cables, each with its own safety fuse. Each of the first ten cables with a 200 A protective fuse has eight (8) tables in parallel, whereas the last line with visible 100 A protection has three (3) tables in parallel. Furthermore, a table is made up of two (02) strings that run in parallel. There are 24 photovoltaic panels(CS6P-250P) in each one. As a result, each Sunny Central 850CP XT inverter manages 3984 panels. Upstream of the photovoltaic inverters are 60 central boxes (junction boxes) in the Ain Skhouna photovoltaic plant.

Three computers are located in the control room. Data from the central and control systems is collected by two of them (inverters, connectors, panels, etc.). The remaining computer is used to monitor the grid's GRTE (Company Network Manager of Electricity Transport) to guarantee that photovoltaic inverters are operating properly. The data

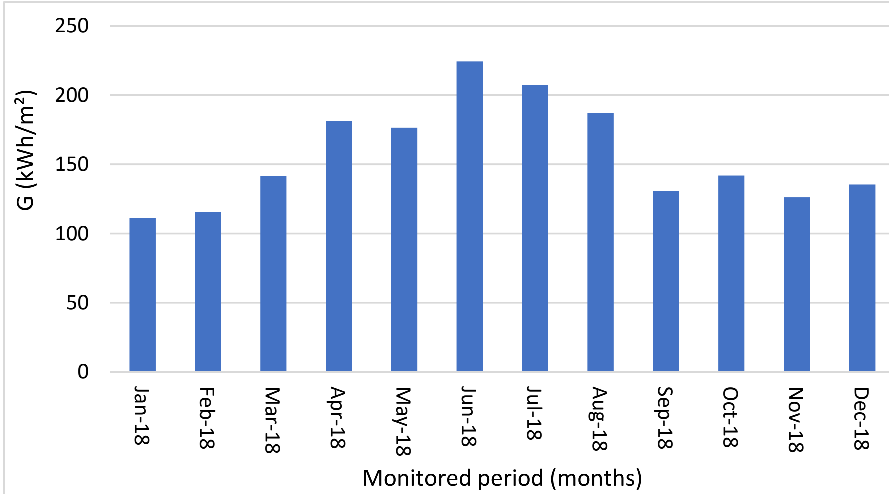

Fig. 1. Monthly solar irradiation (G) evolution in Ain Skhouna (Saida, Algeria).

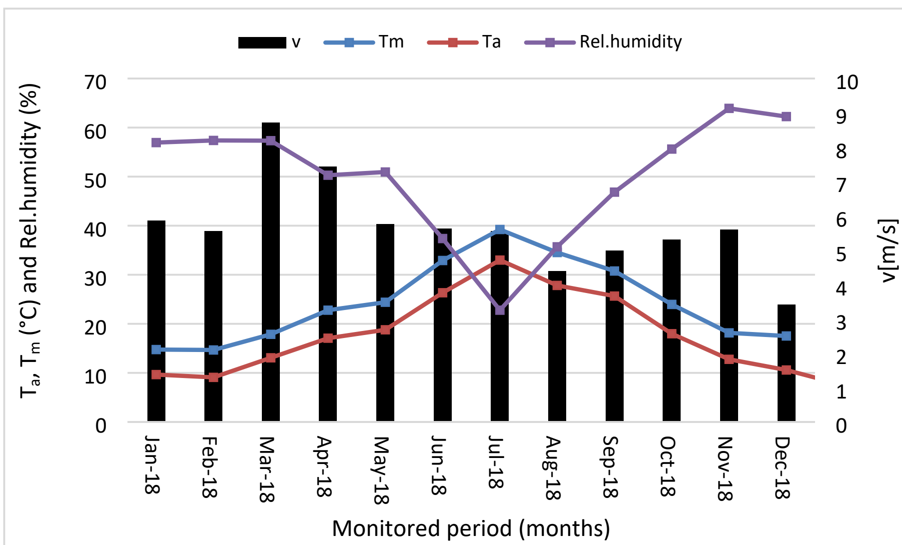

Fig. 2. Monthly temperatures(T_a and T_m), wind speed, and relative humidity evolution in Ain Skhouna (Saida, Algeria).

monitoring system has been designed in accordance with IEC61724. G, T_a, module temperature (T_m), v, and the energy generated by DC and AC (E_{dc} and E_{ac}) are measured instantly every 15 min during the day. The control room meets the IEC 60,529 (Labouret et al., 2010) standard for IP 54 protection, which protects against the filtering of foreign items (such as dust deposits) and negative effects caused by water infiltration.

2.3. Performance parameters description

The international energy agency establishes photovoltaic parameters used in performance studies as described in the IEC 611,724 standard and as reported in the literature(De Lima et al., 2017; Okelloet al., 2015; Daher et al., 2018; Jed et al., 2019; Aoun, 2020, Rabindra et al., 2021, Divineet al., 2021,Dahmoun,et al., 2021). The normalized indicators used are energy generated (E_{dc}), energy fed to the utility grid (E_{ac}), reference yield (Y_r), array yield (Y_a), final yield (Y_f), module efficiency (η_{pv}), inverter efficiency (η_{inv}), system efficiency (η_{sys}), energy loss (array capture loss (L_c) and system loss (L_s)), and PR.

2.3.1. PV array system energy generated (E_{dc})

The following equation is used to determine the daily DC power output ($E_{dc,d}$) value:

$$E_{dc,d} = \sum_{t=1}^{T_{rp}} P_{dc} \times T_r \quad (1.1)$$

In addition, the monthly DC power output ($E_{dc,m}$) is calculated as follows:

$$E_{dc,m} = \sum_{d=1}^{N} E_{dc,d} \quad (1.2)$$

Where T_r,T_{rp}, and N are the recording time offset, the reporting time, and the number of operating days of the plant in a month, respectively.

2.3.2. Energy output (E_{ac})

The energy output (E_{ac}) is a measurement of energy across the inverter output terminals that the data logger records every 15 min. The total daily measured AC energy output ($E_{ac,d}$) is calculated as follows:

$$E_{ac,d} = \sum_{t=1}^{T_{rp}} P_{ac} \times T_r \quad (2.1)$$

The monthly AC energy generated ($E_{ac,m}$) is given as:

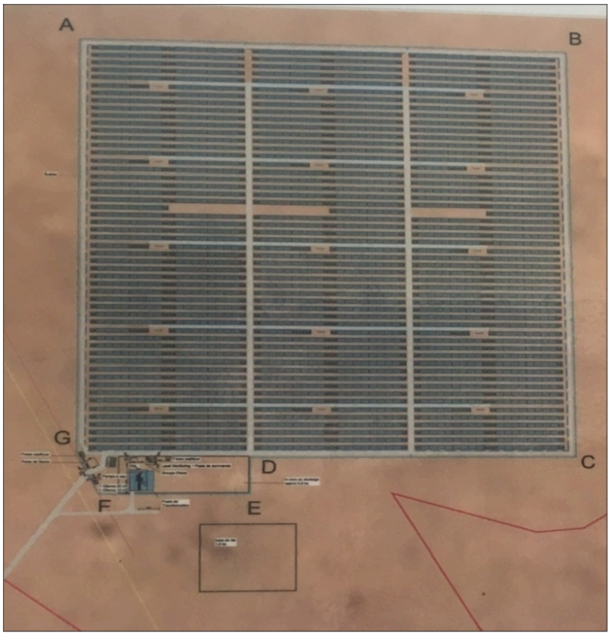

Fig. 3. General scheme of the Ain Skhouna (Saida) PV power plant (Web4).

Table 1
Electrical characteristics of PV modules used in Ain Skhouna power station.

PV module Type	CS6P-250P
Electrical data	
Maximum power (P_{max})	250 W
Voltage for maximum power (V_{mp})	30.1 V
Current for maximum power (I_{mp})	8.30 A
Open circuit (V_{oc})	37.2 V
Short-circuit current (I_{sc})	8.87 A
Temperature coefficient of V_{oc} −0.34%/C	
Temperature coefficient of (Isc)	0.065 %/C
Temperature coefficient of (P_{max})	−0.43 %/C
NOCT	47 ◦C
Efficiency reduction from1000 W/m^2 to 200 W/m^2	+ 96.5 %
Dimensions	
Length	1.638 *m*
Width	0.982 *m*
Weight	18.5 kg
Cells	
Number per module	60
Cell technology	poly-crystalline
Cell size (square)	(0.163*0.163) m^2
Cell yield	15.54 %
Linking cells	3 busbars

$$E_{ac,m} = \sum_{d=1}^{N} E_{ac,d} \tag{2.2}$$

2.3.3. Reference yield (Y_r)

The Y_r is the number of hours in which the total solar irradiation received on the panel surface equals the reference radiation. It's calculated by dividing the amount of received illumination by the amount of reference radiation G_0(1 kW/m^2). It is provided by:

$$Y_r = \frac{H_t}{G_0} \tag{3.1}$$

2.3.4. Array yield (Y_a)

The Y_a is the ratio of total energy generated by E_{dc} (kWh) to nominal power P_0 (kWc) under typical conditions for a certain period (day, month, or year). The yields of the daily ($Y_{a,d}$) and monthly ($Y_{a,m}$) arrays are as follows:

$$Y_{a,d} = \frac{E_{dc,d}}{P_0} \tag{4.1}$$

$$Y_{a,m} = \left(\frac{1}{N}\right) \sum_{d=1}^{N} Y_{a,d} \tag{4.2}$$

2.3.5. Final yield (Y_f)

The Y_f represents the number of hours that the PV array must operate at full power. It is the proportion of total produced energy E_{ac} (kWh) to maximum power P_0 (kWp). The daily and monthly efficiencies ($Y_{f,d}$) and ($Y_{f,m}$) are calculated using the following formulas:

$$Y_{f,d} = \frac{E_{ac,d}}{P_0} \tag{5.1}$$

$$Y_{f,m} = \left(\frac{1}{N}\right) \sum_{d=1}^{N} Y_{f,d} \tag{5.2}$$

2.3.6. PV module efficiency(η_{pv})

The η_{pv}, also known as energy efficiency, is calculated as the ratio of E_{dc} power to solar energy captured. The daily and monthly efficiencies of the η_{pv} achieved are given as follows:

$$\eta_{pv,d} = \frac{E_{dc,d}}{G \times A_m} \times 100 \tag{6.1}$$

$$\eta_{pv,m} = \frac{E_{dc,m}}{G \times A_m} \times 100 \tag{6.2}$$

$E_{dc,d}$ and $E_{dc,m}$ are the daily and monthly energy produced, respectively. G is the solar energy received by the PV system, and A_m is its area.

2.3.7. Inverter efficiency(η_{inv})

The η_{inv} is also used to determine the system's conversion efficiency. It's the ratio of the system's DC power output E_{dc} to its energy output E_{ac}. The monthly η_{inv} is determined as follows:

$$\eta_{inv,m} = \frac{E_{dc,m}}{E_{ac,m}} \times 100 \tag{7}$$

2.3.8. System efficiency(η_{sys})

The η_{sys} refers to the system balance, which includes the PV generator and inverter module. It is given by the following quation:

$$\eta_{sys,m} = \eta_{pv} \times \eta_{inv} \tag{8}$$

2.3.9. Standardized performance index (PR)

The PR, also known as the standardized performance index, expresses the relationship between the Y_f and the Y_r as described in eq. (9). It reflects the effect of losses on the system's energy output.

$$PR = \frac{Y_f}{Y_r} \tag{9}$$

2.3.10. System losses by conversion (L_s)

These losses, which are connected to the conversion of continuous current to alternating current, are recorded in the inverter. As indicated in equation eq. (10), they are expressed as Y_a minus Y_f.

$$Ls = Y_a - Y_f \tag{10}$$

2.3.11. Array capture loss (L_c)

As demonstrated in eq. (11), the L_c is equal to the difference between Y_r and Y_a.

$$Lc = Y_r - Y_a \tag{11}$$

2.4. Data used to assess performance

Weather data such as G, T_a, and v are recorded with a 15-minute time step by a high-precision meteorological station. Indeed, a multi-parameter meteorological sensor (MULTI-5P) was used to measure the following climate parameters: wind speed with a 3% accuracy, ambient temperature with a 0.2 °C accuracy, and relative humidity with a 3% accuracy. A CMP116 pyranometer was used to detect solar irradiation with an accuracy of 0.2 %.

Furthermore, utilizing a real-time embedded capture card connected to the data logger, all electrical properties of the PV system, such as E_{dc}, E_{ac}, and T_m, are recorded with a 15-minute time step. The results discussed in this study cover a year's worth of data, from January 1st to December 31st of 2018.

3. Results and discussion

Monthly T_m variations follow the same pattern as monthly T_a variations. The maximum monthly T_m and T_a were recorded at 39.64 °C and 32.99 °C respectively, during the summer season (July month).The winter season (December) had the lowest monthly Tm and Ta, with values of 13.64 °C and 7.50 °C, respectively. The T_a affects the T_m, and an increase in the T_a induces an increase in the T_m. A linear relationship between these two parameters is given by eq.12, which has a high determination coefficient of 0.994:

$$T_m = 1.032 \times T_a + 5.206 \quad (12)$$

T_m and T_a differed by 6.93 °C in December and 4.79 °C in April, respectively. This is due to a high v value in April, which favors solar module cooling. The v value, on the other hand, was at its lowest in December, resulting in the substantial temperature difference observed.

The monthly average daily evolution of E_{dc} and E_{ac} during the studied period is illustrated in Fig. 4. Both of these energies appear to follow the same pattern. In addition, the E_{dc} is greater than the E_{ac}. The monthly average E_{dc} varied from 3084.24 MWh in January to 5689.025 MWh in June, with the monthly average E_{ac} spreads from 2945.43 MWh (January) to 5493.79 MWh (June).

Fig. 5 shows the monthly average daily Y_r, Y_a, and Y_f yield evolutions. The Y_r varies between 4.35 h (November) and 7.74 h (June). The Y_a ranges from 4.00 h in December to 6.57 h in June. The Y_f takes the highest value of 6.34 h in June and a minimum value of 3.89 h in November and December. The annual Y_f of the PV system is 4.90 h. This value is similar to that recorded for a PV system in Oman (5.1 h) (Kazem et al., 2014) and India (4.81 h) (Padmavathi et al., 2013). It is greater than that recorded in Kuwait (4.5 h) (Al-Otaibi et al., 2015) and Morocco (4.45 h) (Attari et al., 2016).

The monthly average daily losses (L_c and L_s) at this power station over the mentioned period are illustrated in Fig. 6. The L_c has an average value of 0.72 h per day, ranging from 0.31 h per day in January to 1.43 h per day in July. The L_s range from 0.11 h per day in December to 0.28 h per day in September, with a mean of 0.18 h per day. These losses are directly related to the converter efficiency. Furthermore, when the greatest value of September is excluded, these values are reasonably constant, averaging 0.17 h/day. As a result, the PV system's inverters work effectively while converting DC to AC.

As seen in Fig. 7, the high value of L_s in September is due to lower incident G values during this month. Indeed, conversion losses ranged from 99.4 W/m^2 on September 17th to 478.8 W/m^2 on September 1st. Moreover, Fig. 1 shows that the average monthly solar irradiation for September was 361.97 W/m^2, which is lower than the figure for October. The second reason for the high conversion losses is that two inverters in the Saïda 2 field were turned off during September. This technical incident is clearly visible in the η_{inv} evolution shown in Fig. 9. In September, the η_{inv} hits its lowest point of the year.

As shown in Fig. 8, the monthly total loss (L_t), which is the sum of the L_c and L_s losses, rises as the monthly T_a and G rise. Furthermore, L_t varies linearly with T_a and G. The following equation, with a high coefficient of determination of 0.98, can be used to represent the relationship between L_t, T_a, and G:

$$L_t = 0.036 \times T_a + 0.0039 \times G - 0.387 \quad (13)$$

The monthly η_{pv}, η_{sys}, and η_{inv} are shown in Fig. 9. The η_{pv} values range from 12.45% recorded in July to 14.50% registered in January and February. During the study period, the average daily η_{pv} was at 13.78%, which is higher than Morocco's at 12.39% (Attari et al., 2016). The η_{sys} follows the same pace as the η_{pv}. Its average value was 13.29%. Its values range from a minimum of 11.98% in July to a maximum of 14.03%, recorded in January and February. The η_{sys} average value is higher than the value of a Moroccan PV power plant (12.00%) reported by Attari et al., 2016.

The minimum η_{sys} and η_{pv} values recorded in July match the maximum T_m (39.22 °C) and the maximum T_a (32.99 °C) recorded. As the T_a rises, the η_{sys} and η_{pv} decrease, as shown by the following equation:

$$\eta_{sys} = -0.08 \times T_a + 14.78 (R^2 = 0.972) \quad (14.a)$$

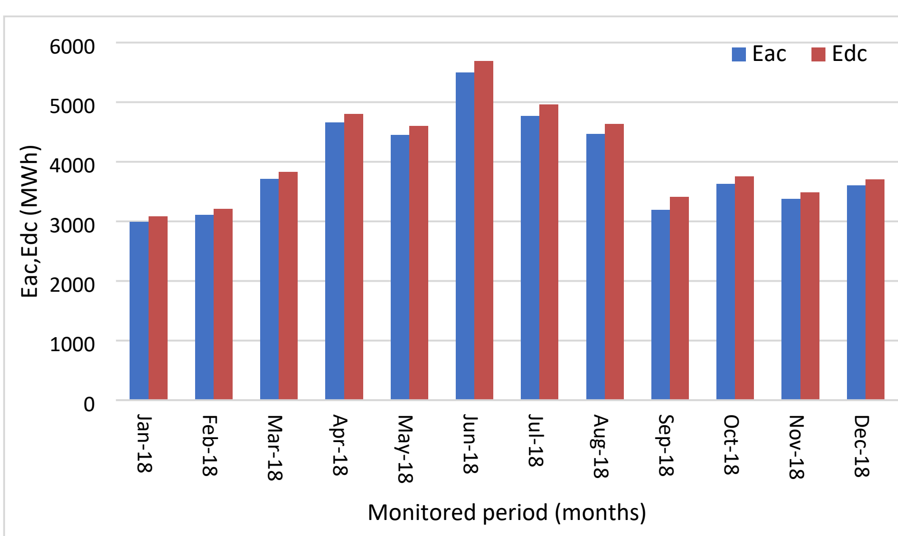

Fig. 4. E_{ac} and E_{dc}energy monthly variations in the Ain Skhouna PV plant (Saida, Algeria).

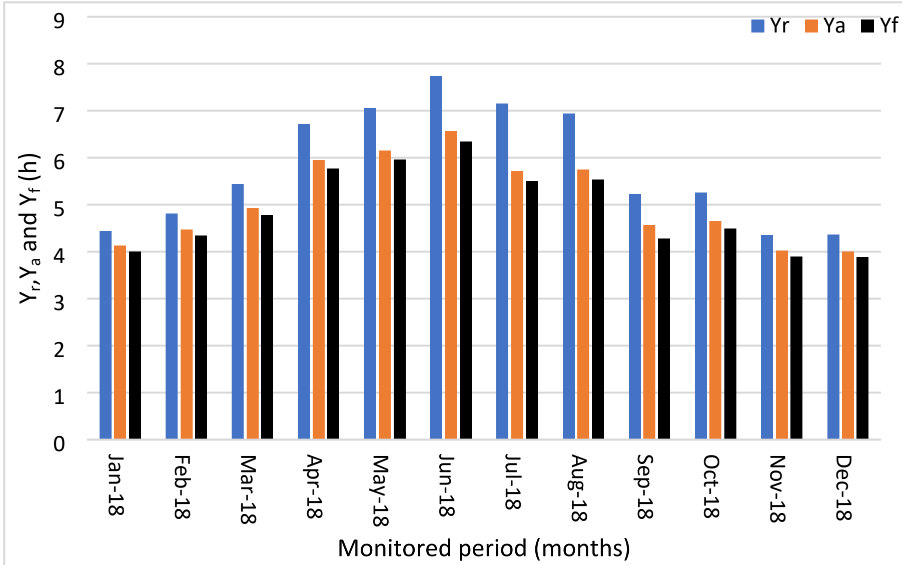

Fig. 5. Monthly variation of yields (Y_r, Y_a, and Y_f) at the Ain Skhouna PV plant (Saïda , Algeria).

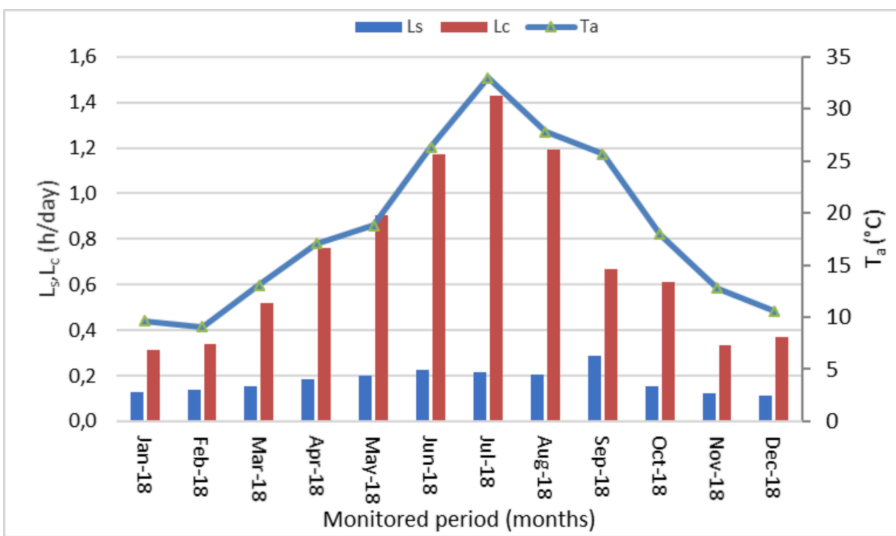

Fig. 6. Monthly variation in losses (L_s and L_c) at the Ain Skhouna PV plant (Saïda , Algeria).

$$\eta_{PV} = -0.076 \times T_a + 15.19 (R^2 = 0.904) \tag{14.b}$$

The monthly η_{inv} values range from 93.94% in September to 97.05% in December. Moreover, Fig. 6 shows that the low η_{inv} value observed in September is attributable to the high L_s found during this month (as mentioned above).

Without taking September into account, the average η_{inv} value for the analysed time is around 96.68%. This figure is said to be in the [95%-98%] range as reported by Fujisawa et al., 2001. It is similar to that reported by Attari et al., 2016 in Morocco (96.7%) and higher than that reported by Sundaram et al., 2015 in South India (88.2%). Furthermore, it was noted that the η_{inv} was affected by G, as seen in September, but not by T_a.

The PR is the most important primary parameter used for comparing different solar power plants. It indicates the overall effect of L_s, which includes converter losses, losses due to non-STC temperature, wire losses, losses due to the cell, chain, and network mismatch, shading losses, and losses due to fouling, on the nominal output. The evolution of the monthly average daily PR of this power plant is illustrated in Fig. 10. It ranges from 77.08 % in July to 90.26 % in February. The monthly average daily PR is estimated at 85.52%, which means that 14.48% of the incident solar energy is not converted to electricity due to the different losses cited above. This parameter is proportional to η_{sys} and η_{pv}, and it is inversely proportional to T_m and T_a. A relationship between PR and T_a with a high correlation coefficient can be proposed as:

$$PR = -0.519 \times T_a + 95.12 (R^2 = 0.972) \tag{15}$$

The PR found in the literature is within the range of 0.5 to 0.9 (Attari et al., 2016; Mensah et al., 2019; Sidi et al., 2016; Wichliński et al., 2018; De Lima et al., 2017; Daher et al.,. 2018; Jed et al., 2019). Moreover, the monthly PR of the 2.5 MW solar PV power plant installed in Navrongo (Ghana) varied between 61.8% and 76.9%, with an average value of 70.6%. These values represent the level of losses experienced by these PV plants, which can be attributed to wire system resistance losses, dust soiling, high ambient temperatures, and low wind speeds (Mensah et al., 2019). At the Sheikh Zayed solar power plant in Nouakchott, two arrays (array 1 and 17) had lower PR values as well. Array 1′s monthly PR ranged from 63.59% to 73.56%, with an average of 67.96% percent (Sidi

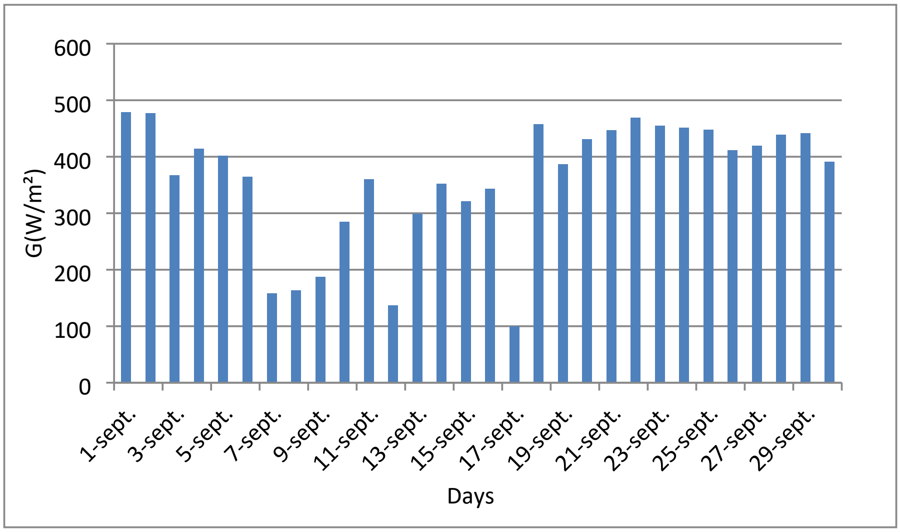

Fig. 7. G evolution on a daily basis during the month of September.

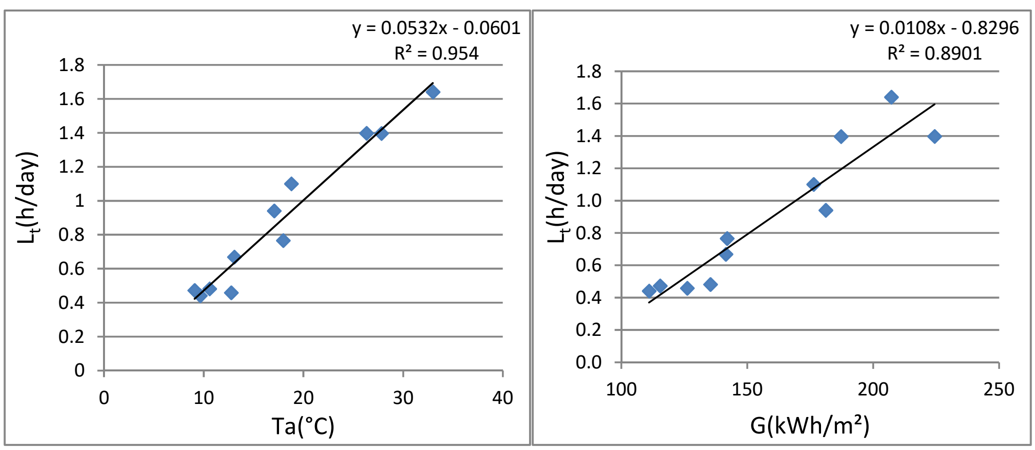

Fig. 8. Monthly T_a and G variations impact on total losses.

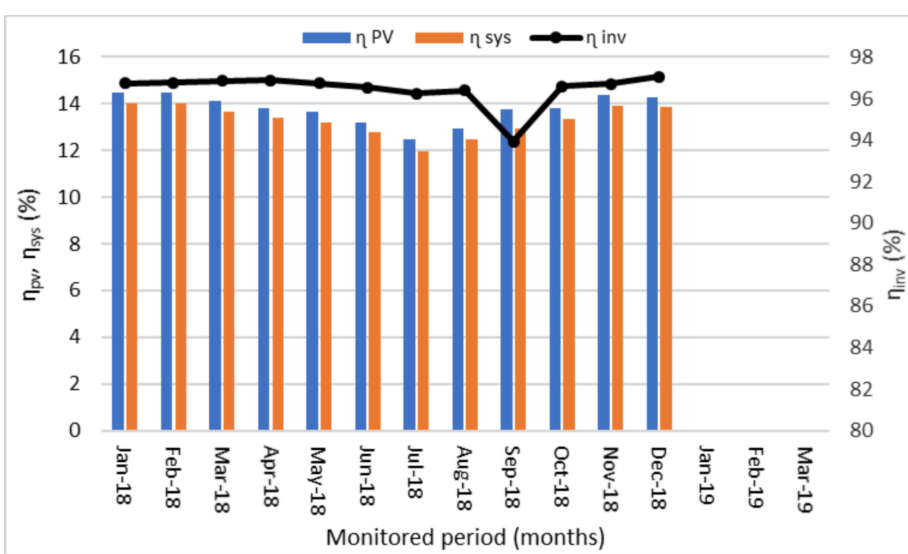

Fig. 9. Monthly variation of efficiencies (η_{pv}, η_{sys}, and η_{inv}) at the Ain Skhouna PV plant (Saïda, Algeria).

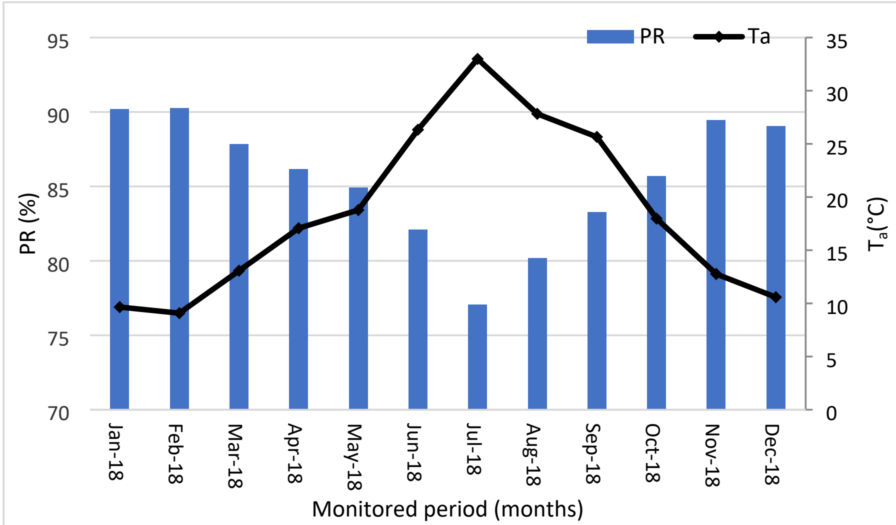

Fig. 10. Monthly variation in PR at the Ain Skhouna PV plant.

et al., 2016). Another lower value is recorded for the car park in Cairo (Egypt), where the monthly PR values ranged between 51.7% and 72.7% (Wichliski et al., 2018). On the other hand, the monthly performance ratio of the 2.2 MWp grid-connected photovoltaic system installed at the State University of Ceara (Brazil) ranged from 72.9% to 91.9%, with an average value of 82.9% (De Lima et al., 2017). In addition, the measured monthly PR of the 3.2 kWp grid-connected PV system in Port Elizabeth, South Africa (Okelloet et al., 2015) varied from 81% to 86%, with an annual mean value of 84.3%. For the 302.4 kWp PV grid-connected power plant in Djibouti (Daheret et al., 2018), the monthly PR ranged from 71% to 91%, with an average value of 84%.

The influence of T_a and G on the performance of this PV power plant was investigated using a seasonal analysis. The total G, T_a, and v for each season are shown in Table 2. Summer has the highest levels of G and T_a, while winter has the lowest. The winter season has the lowest v value (4.92 m/s), the spring season has the highest value (7.30 m/s), and the summer (5.19 m/s) and fall (5.30 m/s) seasons have moderate values.

Because the monthly T_m and T_a are linearly related, summer has the highest seasonal T_m, followed by autumn and spring, while winter has the lowest. The seasonal average monthly E_{dc} and E_{ac}, like the seasonal G, follow the same trend. As seen in Table 2, these parameters have maximum values in the summer and minimum values in the winter.

As shown in Table 3, all seasonal variations in yields (Y_r, Y_a, and Y_f) are proportional to G, with maximum values in summer (7.27 h, 6.01 h, and 5.79 h, respectively) and minimum values in winter (4.54 h, 4.2 h, and 4.07 h, respectively. The maximum seasonal η_{pv} (14.42%) and η_{sys} (13.96%) were recorded in the winter. As previously stated, these values were recorded at the lowest temperature, T_m (15.64 °C). In the summer season, with a higher T_m (35.55 °C), the lowest seasonal η_{pv} (12.86%) and η_{sys} (12.4%) were observed. The seasonal η_{inv} was higher (96.85%) in the winter and lower (95.75%) in the autumn, with the latter being related to the lowest value of η_{inv} recorded in September.

The L_c measured in the winter was the lowest (0.34 h/d), while the L_c measured in the summer was the highest (1.26 h/d). The maximum L_c can be related to the highest T_a observed throughout the summer season. According to the monthly analysis, the L_t was higher in the summer season (1.48 h/d) due to the higher seasonal G (206.28 kWh/m^2) and the higher seasonal T_a (29.05 °C). In contrast, winter had the lowest L_t (0.46 h/d), which was associated with lower seasonal G (120.62 kWh/m^2) and lower seasonal T_a (9.77 °C). Because L_c has such a strong influence on PR, the highest PR was recorded in the winter season (89.85%) and the lowest in the summer season (79.79%). As a result, the PV power plant worked better in the winter than in other seasons, but not so well in the summer. Furthermore, the spring and autumn seasons had similar PR values of 86.31% and 86.15%, respectively.

Table 2
Seasonal value of G, T_m, T_a, v, E_{dc}, and E_{ac}.

Seasons	G (kWh/m^2)	T_a(°C)	T_m(°C)	v(m/s)	E_{dc}(MWh)	E_{ac}(MWh)
Winter	120.62	9.77	15.64	4.94	3331.84	3232.71
Spring	166.37	16.31	21.68	7.30	4408.73	4271.08
Summer	206.28	29.05	35.55	5.19	5092.6	4910.71
Autumn	132.97	18.80	24.29	5.30	3545.96	3397.59

The Ain Skhouna PV power plant (30 MW), which is located in a semi-arid region, was compared to the Adrar PV power plant (20 MW) (Aoun, 2020), which is located in a hot desert climate (hyper-arid) typical of the Saharan zone.

The monthly average daily T_a in the Adrar region ranges from 14.05 °C in December to 40.8 °C in July (July). In comparison to the other months, the months of May, June, July, August, and September have a higher T_a. As shown in Fig. 11, the Adrar region is hotter than Saïda. In other words, the average monthly temperature in Adrar is greater than in Saïda. Indeed, the temperature difference is higher in summer. It is above 8 °C and can reach 10.86 °C. The G at the Adrar site ranges from 171.7 kWh/m^2 (January) to 251.2 kWh/m^2 (May).

Maximum G values of over 150 kWh/m^2 were recorded during the spring and summer seasons (March, April, May, June, July, and August). The maximum incident solar irradiation difference between these two sites was roughly 90 kWh/m^2 in March, whereas the smallest difference was 19 kWh/m^2 (June). The incident solar irradiation in Adrar is higher than that in Saïda.

As illustrated in Fig. 11, the daily average monthly v ranges between 3.59 m/s (October) and 5.14 m/s (April) for the Adrar site. The v in the Saïda site is higher than that of the Adrar site, except for two months, which are August and December. Thus, we can say that Saïda is windier than Adrar.

As illustrated in Fig. 12, the L_t varies between 1.06 h (January) and 3.55 h (July) at the Adrar PV power plant. These values are higher than those of the Ain Skhouna PV power plant, which range from 0.44 h (January) to 1.64 h (July). The L_t reaches its maximum levels in the months of April, May, June, July, and August. As previously stated (Eq.13), when T_a and G are higher, the L_t is higher. Furthermore, as shown in Fig. 12, a high L_t reduces η_{sys} and PR.

At the Adrar PV power plant, the η_{sys} ranges from 8.34% (July) to 12.37% (January). These η_{sys} values are lower than those of the Ain Skhouna PV power plant, which vary from 11.98% (July) to 14.03%

Table 3
Seasonal yields, efficiencies, losses, and PR.

Seasons	Yields (h)			Efficiencies (%)			Losses (h/d)		
	Y_r	Y_a	Y_f	η_{PV}	η_{sys}	η_{inv}	L_s	L_c	PR
Winter	4.54	4.2	4.07	14.42	13.96	96.85	0.13	0.34	89.85
Spring	6.4	5.68	5.5	13.86	13.41	96.82	0.18	0.73	86.31
Summer	7.27	6.01	5.79	12.86	12.4	96.39	0.21	1.26	79.79
Autumn	4.95	4.41	4.22	13.98	13.39	95.75	0.19	0.54	86.15

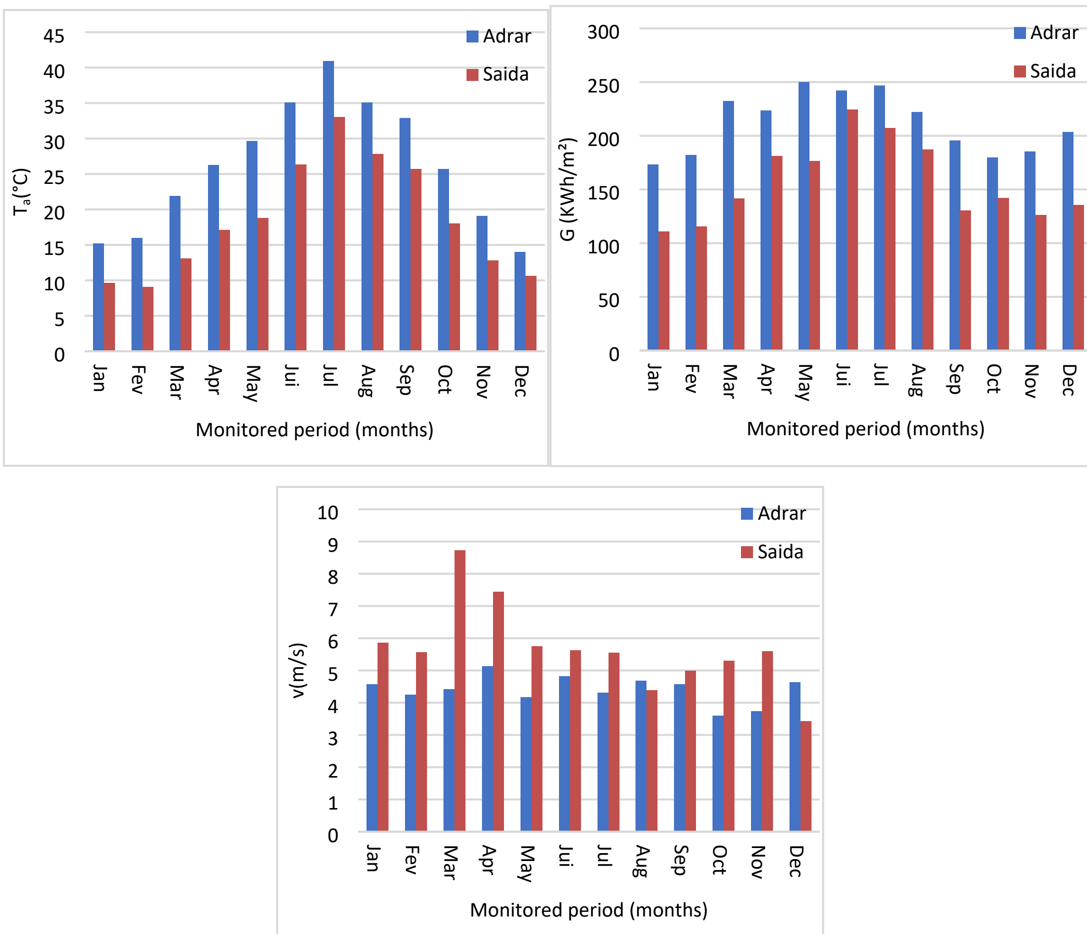

Fig. 11. Comparison of T_a, G, and v between the two sites studied (Saïda and Adrar).

(February) as shown in Fig. 12. The difference in the η_{sys} between the two power plants reaches high values during the months of May (3.40%), June (3.55%), and July (3.50%). The greatest L_t values are responsible for this outcome.

The PR values at the Adrar PV power plant range from 55.29% (July) to 81.96% (January), with an average value of 71.71%, as seen in Fig. 12. These values are lower than those of the Ain Skhouna PV power plant, where the PR varies from 77.26% (July) to 90.26% (February), with an average value of 86.23%. Thus, across the research period, the PR of the Adrar PV power plant is lower than that of the Saïda PV power plant. The performance ratio disparity between the two stations reaches high levels during the months of May (19.97%), June (20.89%), and July (21.33%), which can be related to the low L_t values reported during these months.

The rise in ambient temperature, incident solar irradiation, and the effect of dust are the main causes of decreasing PR in Adrar.

A seasonal comparison was conducted between the two power plants in Saïda and Adrar, which have different climatic conditions. G and T_a in Adrar are higher than in Saïda for different seasons, as noted in Table 4, which is in accordance with the monthly results. At both sites, the summer season is marked by higher G and T_a values, whereas the winter season is marked by lower values. During the four seasons, Saïda is windier than Adrar, with high winds in the spring and low winds in the fall.

As shown in Table 5, the measured values of G and T_a have a direct impact on L_t, which is higher in the Adrar power plant than in Saïda power plant. Indeed, the highest L_t is recorded in summer (1.57 h/day), followed by spring (1.34 h/day) and autumn (0.84 h/day). The lowest value of 0.75 h/d is recorded in the winter season. As a result, the η_{sys} and PR in Adrar are lower in all seasons than in Saïda. The two photovoltaic power plants, Saïda and Adrar, perform best during the winter months. In fact, as shown in Table 5, the best performances (η_{sys} (13.96% and 12.12%)) and PR peaks (89.58% and 80.65%) are obtained in the winter. On the other hand, the summer season is the bad season with low performance levels.

η_{sys} of 11.43% and 10.71% are observed in Adrar during the fall and

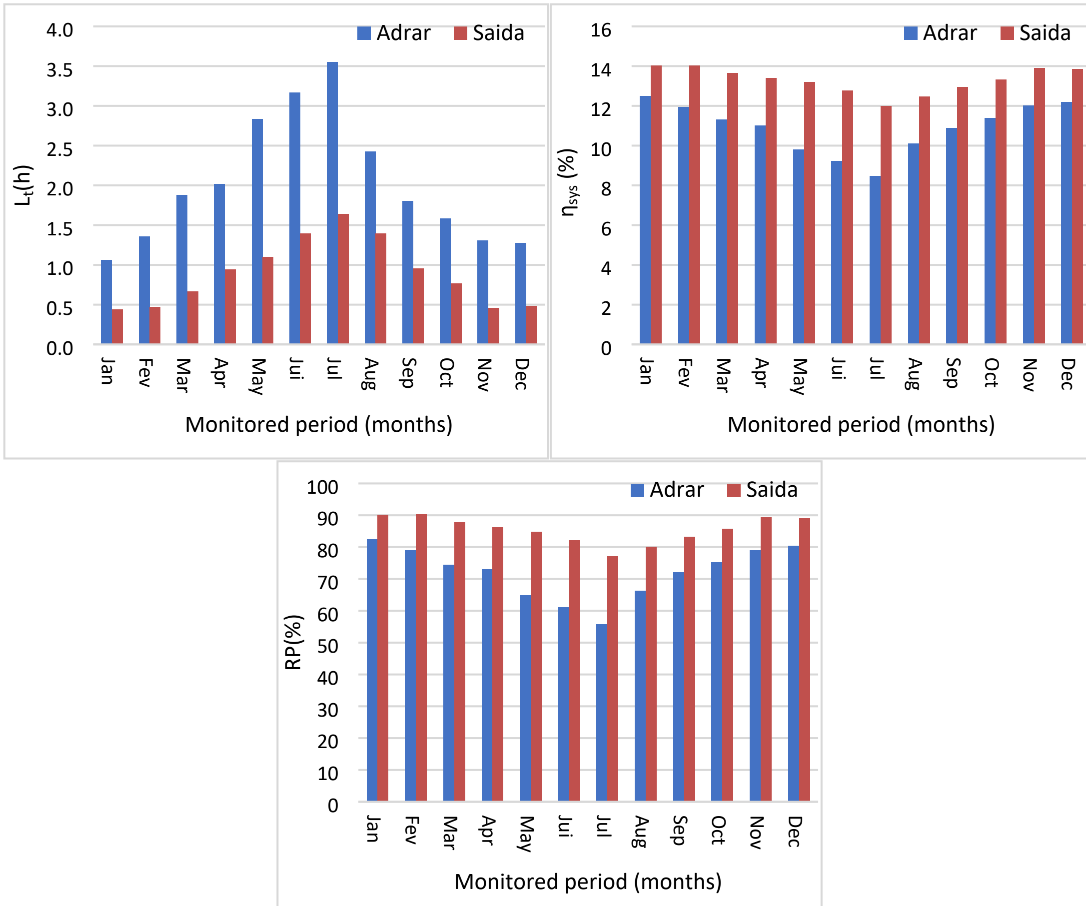

Fig. 12. L_t, η_{sys}, and PR comparison between Adrar and Saïda PV power plants.

Table 4
Comparison of seasonal weather parameters between Adrar and Saïda.

Seasons	G (kWh/m^2)		T_a(°C)		v(m/s)	
	Saïda	Adrar	Saïda	Adrar	Saïda	Adrar
Winter	120.62	186.30	9.77	15.03	4.94	4.49
Spring	166.37	235.19	16.31	25.94	7.30	4.57
Summer	206.28	237.04	29.05	37.01	5.19	4.6
Autumn	132.97	187.04	18.80	25.87	5.30	3.97

Table 5
Seasonal L_t, η_{sys} and PR comparison between Adrar and Saïda power plants.

Seasons	L_t(h/d)		η_{sys}(%)		PR(%)	
	Saïda	Adrar	Saïda	Adrar	Saïda	Adrar
Winter	0.46	1.21	13.96	12.12	89.58	80.65
Spring	0.90	2.24	13.41	10.71	86.31	70.79
Summer	1.48	3.05	12.40	9.27	79.79	61.11
Autumn	0.73	1.56	13.39	11.43	86.15	75.48

spring seasons, respectively. PR, on the other hand, takes the values of 75.48% and 70.79%, respectively. In Saïda, η_{sys} of 13.41 % and 13.39 %, are observed during the spring and fall seasons, respectively. PR, on the other hand, takes the values of 86.31% and 86.15%, respectively. It should be noted that at the Saïda PV plant in both spring and autumn, similar values for η_{sys} and PR are recorded, which can be attributed to the high v (7.3 m/s, see Table 4) during the spring season, which favors PV panel cooling.

The climatic conditions have an important effect on PV performance. The installation sites for PV plants must be chosen according to environmental conditions. It is true that solar irradiation is the key criterion in the installation of PV or thermal plants. However, the high temperatures caused by the high solar irradiation intensities elevate the T_m and the L_t while lowering the η_{sys} and PR. As a result, measures to minimize PV module temperature and dust are needed to increase the performance of PV plants previously erected in the desert zone.

4. Conclusion

Ain Skhouna PV power plant (30 MWp) located in Saïda (Algeria) is presented as a solar energy application for electricity production. This study is focused on its performance evaluation during the 2018 year, according to the norm IEC 61724. The most important parameters that affect this performance are also evaluated.

The monthly energy generated E_{dc} ranges from 3084.24 MWh (January) to 5689.025 MWh (June), and the monthly variation of daily average output energy spreads from 2945.43 MWh (January) to 5493.79 MWh (June). These two energies are linearly proportional to the insolation. The annual reference, array, and final yields are 5.79, 5.07, and 4.90 h, respectively. The annual capture and system losses are about 0.72 h/d and 0.18 h/d, respectively. The mean monthly PV, system, and inverter efficiencies are 13.78%, 13.29%, and 96.68%, respectively. The mean monthly performance ratio is 85.52%, which is comparable to that of other PV power plants throughout the world.

The ambient temperature has a greater impact on this power plant's monthly and seasonal performance than solar irradiation or wind speed. Winter is the best season for its performance, followed by spring, fall, and finally summer.

The effect of climate on PV plant performance was investigated by comparing two PV plants in Algeria: Ain Skouna (Saïda), which has a semi-arid environment, and Adrar, which has the typical hot desert climate of the Saharan zone (hyper-arid). Adrar zone receives more total solar irradiation, has a higher ambient temperature, and is less windy than Saïda zone. According to the monthly analysis, Adrar PV plant has higher overall losses than Saïda PV plant, which has a higher system efficiency and performance ratio. The months of April, May, June, July, and August have the highest total losses at Adrar plant, which can be linked to the maximum ambient temperature and total solar irradiation. The system's efficiency and performance ratio decrease as a result of the high temperatures.

According to the ambient temperature, the winter season at both power plants is the best, with higher system efficiency and performance ratios, while the summer season is the worst, with low performance levels.

As a result, for PV power plant electricity production, a semi-arid climate is preferred over a desert climate. Indeed, the efficiency of a PV plant is influenced by the ambient temperature more than solar irradiation. This explains why the PV plant in Ain Skhouna was placed first in Algeria's PV plant classification.

At both power plants, the winter season was the best, with higher system efficiency and performance ratios, while the summer season was the worst, with low performance levels, according to the ambient temperature. As a result, for PV power plant electricity production, a semi-arid climate is preferred over a desert climate. Indeed, the efficiency of a PV plant is influenced by the ambient temperature more than solar irradiation. This explains why the PV plant in Ain Skhouna is placed first in Algeria's PV plant classification.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to acknowledge Mr. Saadi Idir, SKTM Human Resources Department Head, for giving access to Ain Skhouna PV plant. We would like to think all Ain Skhouna PV plant personnel particularly Hamel Cheikh for they help.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Jaydeep, V.R., 2015. Performance Evaluation of Grid-connected Solar Photovoltaic plant using PVSYST Software. J. Emerg. Technol. Innov. Res. (JETIR) 2 (2), 372–378.

Iftakhar, U.T.M., Abrar, S.M., Husnain-A, B., Zakaria, M.M., 2012. Computational Modeling of a GRID Connected System Using PVSYST Software. Int. J. Sci. Eng. Res. 3, 2012.

Al-Bustam, H., Zakaria, M.Md., Shuvro, S.M.M.,Iftakhar, U.T.M,. Abrar, S.Md. (2012), "Analysis of a Standalone Photovoltaic Power Generation System Using PVSYST Software", *Global Journals Inc. (USA)*, Vol. 12.

Al-Otaibi, A., Al-Qattan, A., Fairouz, F., Al-Mulla, A., 2015. "Performance evaluation of photovoltaic systems on Kuwaiti schools' rooftop". Energy Convers. Manage. 95, 110–119.

Kazem, H.A., Khatib, T., Sopian, K., Elmenreich, W., 2014. Performance and feasibility assessment of a 1.4 kW roof top grid-connected photovoltaic power system under desertic weather conditions. Energy Build. 82, 123–129. https://doi.org/10.1016/j.enbuild.2014.06.048.

Attari, K., Elyaakoubi, A., Asselman, A., 2016. Performance analysis and investigation of a grid-connected photovoltaic installation in Morocco. Energy Rep. 2, 261–266.

Padmavathi, K., ArulDaniel, S., 2013. Performance analysis of a 3 MW_p grid connected solar photovoltaic power plant in India. Energy Sustain. Develop. 17 (6), 615–625.

Sundaram, S., Babu, J.S.C., 2015. Performance evaluation and validation of 5 MWp grid connected solar photovoltaic plant in South India. Energy Convers. Manage. 100, 429–439.

Mensah, L.D., Yamoah, J.O., Adaramola, M.S., 2019. Performance evaluation of a utility-scale grid-tied solar photovoltaic (PV) installation in Ghana. Energy Sustain. 48, 82–87.

Sidi, C.E.B.E., Ndiaye, M.L., El Bah, M., Mbodji, A., Ndiaye, A., Ndiaye, P.A., 2016. Performance analysis of the first large-scale (15 MWp) grid-connected photovoltaic plant in Mauritania. Energy Convers. Manage. 119, 411–421.

Wichliński, M.,Staszkiewicz, J.(2018),"Photovoltaic installation for a roofed car park in Egypt as an example of effective use of solar energy",*E3S Web of Conferences* , Vol. 49,00127.

de Lima, L.C., de Araújo Ferreira, L., de Lima Morais, F.H.B., 2017. Performance analysis of a grid connected photovoltaic system in northeastern Brazil. Energy Sustain. Develop. 37, 79–85.

Okello, D., van Dyk, E.E., Vorster, F.J., 2015. Analysis of measured and simulated performance data of a 3.2 kWp grid-connected PV system in Port Elizabeth, South Africa. Energy Convers. Manage. 100, 10–15.

Daher, D.H., Gaillard, L., Amara, M., Ménézo, C., 2018. Impact of tropical desert maritime climate on the performance of a PV grid-connected power plant. Renew. Energy 125, 729–737.

Jed, M.El.H., Ihaddadene, R., Ihaddadene, N., Sidi,C.E.B.E., EL.Bah, M. (2019)"Performance analysis of 954,809 kWp PV array in Sheikh Zayed solar power plant (Nouakchott, Mauritania)",*Renewable Energy Focus*, Vol.32, pp.45-54. Web1: https://www.algerie-eco.com/18/04/04/energie-solaire-lalgerie-enfin-determinee-a-exploiter-son-enorme-potentiel/ Web2:http://www.lemaghrebdz.com/?page=detail_actualite&rubrique=Internationnal&id=85647 Web3:http://www.sktm.dz/?page=article&id=56.

Aoun, N.(2020)"Performance Analysis of a MW Grid-Connected Photovoltaic Installation in Adrar, South of Algeria". Chapter book in Advanced Statistical Modeling, Forecasting, and Fault Detection in *Renewable Energy Systems*: Fouzi Harrou & Ying Sun (ed.) in. IntechOpen.

Rabindra, S., Venkateswarlu, P.(2021) "Chapter 10 - Grid integration, performance, and maintenance of solar PV power systems", *Solar PV Power Design, Manufacturing and Applications from Sand to Systems,* pp. 435–481.

Divine, A., Istvan, S., Istvan, F., 2021. The state of solar PV and performance analysis of different PV technologies grid-connected installations in Hungary. Renew. Sustain. Energy Rev. 141 (110808), 1–9.

Dahmoun, M.-H., Bekkouche, B., Sudhakar, K., Guezgouz, M., Chenafi, A., Chaouch, A., 2021. Performance evaluation and analysis of grid-tied large scale PV plant in Algeria. Web4: Energy Sustain. Develop. 61, 181–195.

Labouret, A., Cumunel, P., Faraggi, J.-paul B.B.(2010) "Cellules solaires Les bases de l'énergie", Dunod ; Paris.

Fujisawa, T., Tani, T., 2001. Optimum design for residential photovoltaic-thermal binary utilization system by minimizing auxiliary energy. Electr. Eng. Jpn. 137 (1), 28–35.