Performance analysis of the 10 MWp photovoltaic plant of Tozeur in Tunisia

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Abstract— In this work, we present the performance of a solar photovoltaic plant located in Tozeur (Tunisia). This solar power plant connected to the HTA network of the Tunisian Electricity and Gas Company (STEG) is equipped with photovoltaic panels based on monocrystalline technology. By analyzing the performance indicators, it is possible to predict the limits and the constraints on the energy production and also to assess the environmental impact on the operating of this type of installation. For this purpose, sufficient data were collected over a period of 30 days for the analysis of the climate and of the performance parameters. The results obtained showed a satisfactory performance of the PV plant with a performance ratio (PR) of 86.32%, close to that of other plants also operating in desert conditions.

Keywords— Solar PV plants, desert climate, monitoring, performance ratio.

I. INTRODUCTION

Photovoltaics (PV) is one of the most promising technologies to address the global challenge of climate degradation and the pressing need for green renewable energy and sustainable development. Fossil fuels emit CO_2 and their reserves are limited, unlike for renewable energies. By receiving light from the sun, photovoltaic solar panels produce power throughout the day. The solar panels are easy to install, require very little maintenance, and can have a long lifespan of up to 35 years. Besides, a photovoltaic installation could be a profitable investment for individuals and companies, namely in high solar potential countries such as in Tunisia.

Several authors have analyzed the performance of grid-connected solar PV plants under different climatic, geographical and environmental conditions for several PV module technologies. Indeed, Ayompe et al. [1] conducted a study on a photovoltaic system installed on the roof of the Focas Institute building of the Dublin Institute of Technology in Ireland. The 1.72 kWp photovoltaic system used 215 Wp photovoltaic panels and consists of 722 thin monocrystalline silicon solar cells surrounded by ultra-thin amorphous silicon layers. The experimental data were recorded from November 2008 to October 2009, and revealed that the total annual energy generated was 885.1 kWh/kWp and that the performance ratio was 81.5%. Muyiwa et al. investigated the performance of a grid-connected PV system on a flat area of a laboratory building at the Norwegian University of Life Sciences in Norway [2]. The results acquired were based on data production recorded from March 2013 to February 2014. The total annual production supplied to the grid was found to be 1927.7 kWh with an annual specific yield of 931.6 kWh and a monthly average energy production of 160.6 kWh. The daily average annual array efficiency, the final efficiency and the PV reference efficiency were estimated at 2.73 kWh/kWp, 2.55 kWh/kWp and 2.80 kWh/kWp respectively. Kymakis et al. presented the performance rating of a grid-connected PV park in Sitia, Crete [3]. This PV park had a capacity of 171.36 kWp and used 120W polycrystalline silicon PV modules. The solar plant supplied 229 MWh to the grid in 2007 with a performance ratio ranging from 58% to 73%. Khatib et al. studied the performance and characteristics of a 5 kWp grid-connected PV system located in Malaysia [4]. This solar power plant involved 120W multicrystalline photovoltaic modules. The operating performance data was recorded from 1 to 31 October 2011. The experimental results showed that the average PV performance was 73.12% while the average inverter performance was 98.56%. Al-Otaibi et al. reported the performance measurement of grid-connected PV systems on the roofs of two schools in Kuwait, 85.05 kWp for the Azda school and 21.6 kWp for the Sawda school [5]. Both the systems were monitored and the data were collected from January 2014 to December 2014. The photovoltaic modules used were copper indium gallium selenide (CIGS) thin films with a power of 150 Wp. The results showed that the performance ratio was maintained between 74% and 85%. Okello et al. presented in their study the performance analysis of a 3.2 kWp grid-connected photovoltaic field located in South Africa [6]. The system consisted of 230W polycrystalline silicon modules. The analysis of the measured data in 2013 indicated that the system supplied a total of 5757 kWh/year to the grid with a performance rate of 84%. Lastly,

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Bouaichi et al. provided the results of an investigation on the long-term performance, the degradation, and the cost analysis of three different PV module technologies-monocrystalline silicon (m-Si), polycrystalline silicon (p-Si), and amorphous silicon (a-Si), all operating under desert conditions in Errachidia, Morocco [7]. The main aim was to determine the most suitable module technology for this kind of environment. The performance ratio (PR), the degradation rate (Rd) and the levelized cost of energy (LCOE) of the indicators were determined for each installed PV technology. The results revealed that the p-Si technology had the best performance with the highest PR of 82.54 ± 5.84% compared to 82.24 ± 4.77% for m-Si and 81.36 ± 3.79% for a-Si although the p-Si technology could be prone to faster degradation.

The objective of this work is to study the performance of a photovoltaic power plant of 10 MWp, located in Tozeur (Tunisia). A relevant set of experimental data was collected over a period of one month. The meteorological and energy production data recorded by the monitoring system were used to calculate the performance parameters specified in the International Electrotechnical Commission (IEC) 61724 standard. The performance of the PV system was examined by viewing and commenting on the various calculated indicators. In particular, the losses in the energy production were quantified and the performance of the PV plant was compared with that of other plants functioning in a desert environment as well.

II. PHOTOVOLTAIC PLANT

The 10 MWp photovoltaic plant of Tozeur-2 (figure 1) was connected to the STEG network via a 150 kV substation in 2018. It consists of ten subfields of PV modules, five transformer substations "PTR" each containing two inverters, one delivery substation "PDL" (involving a shielded substation, auxiliary transformers, generators, TGBT tables, batteries and chargers), cable networks, four meteorological stations, a storage building and two watchtowers.

The PV modules are oriented towards the South with a tilt angle of 30° and an inter-row space of 5.4 m to obtain an annual electricity production guaranteed by the manufacturer at the metering point of 18.823 GWh. The Jinko Solar panels used are of monocrystalline type (see table 1). The total number of modules is 28994, each module consisting of 72 cells and having a power of 345 Wp. Four WS510-UMB compact weather stations were implanted near the inverter cabins in order to measure the air temperature, the relative humidity, the solar irradiance, the air pressure and the wind direction and speed. A Modbus RS485 interface was connected to the weather data logger. Besides, the inverters are of type INGETEAM 1140TL B410, having a maximum entry voltage of 1050 V and an entry current of 2000 A at MPPT.

Fig. 1. Photovoltaic plant of Tozeur 2.

TABLE I. MAIN TECHNICAL CHARACTERISTICS OF A JINKO SOLAR MODULE TAKEN FROM ITS DATASHEET (STC CONDITIONS)

Technology	Monocrystalline
Solar module type	JKM345M-72
Maximum power	345 W
Maximum power voltage	38.9 V
Maximum power current	8.87 A
Open-circuit voltage	47.3 V
Short-circuit current	9.31 A

III. METHODOLOGY

A. Performance Indicators

The energy flow conversion chain in a grid-connected photovoltaic system depends on environmental factors such as the solar irradiance incident on the panels, the ambient temperature, the module temperature and the wind speed. Therefore, in order to analyze the performance of a PV system, performance parameters have been specified by the International Energy Agency (IEA) and are described in the IEC 61724 standard [8,9] These parameters can be relevant for defining the overall system performance in terms of energy production, solar resources and PV system losses. The calculated performance indicators give a more balanced insight into the actual operation of a PV plant, as they account for the different operating conditions of each plant.

B. Reference yield: Y_r

The reference yield Y_r expressed in hours (h) corresponds to the ratio of the total in-plane solar insolation H_t (in kWh/m^2) to the reference irradiance G (i.e. 1 kW/m^2):

$$Y_r = \frac{H_t}{G}. \quad (1)$$

C. Final PV system yield: Y_f

The final yield Y_f is defined as the net AC energy output E_{AC} for a given period divided by the DC power of the PV array P_0 rated at Standard Test Conditions (STC). Y_f is expressed in hours (h) or kWh/kWp [9]. It represents the number of hours per day that the photovoltaic generator operates at its nominal power:

$$Y_f = \frac{E_{AC}}{P_0}. \quad (2)$$

Y_f is an important indicator that allows the normalization of the energy produced in accordance with the PV system size. Y_f is notably affected by the mounting structure, the orientation and the location of the installed PV system. In addition, Y_f is a convenient parameter for comparing the produced energy of various PV arrays installed in the same conditions having different sizes [8].

D. Specific yield: Y_a

The specific yield Y_a expresses the measure of the total energy generated per kWp installed in a given time frame (noted a). This measure is usually calculated for the DC energy produced E_{DC} and the AC energy E_{AC} measured by the plant:

$$Y_a = \frac{E_{DC}}{P_0}. \quad (3)$$

In both cases, it indicates the number of full power equivalent hours for which the plant produces during the given period. The importance of this measure lies in the fact that it normalizes the deliverability of power plants over a given period and hence allows the comparison of the production of power plants with different capacities or even different technologies (PV, wind, biomass, etc.). In addition, the inverter-level calculation enables a direct comparison between the inverters, which may have different AC/DC conversion rates or power ratings.

E. Performance Ratio: *PR*

The performance ratio PR is defined as the ratio between Y_f and Y_r. This parameter is dimensionless and PR makes it possible to compare PV systems regardless of their location, tilt angle, orientation and installed capacity. It shows the incomplete utilization of incoming solar radiation and the proportion of energy available at the grid after losses in the PV systems [10]. The performance ratio is given by the following expression:

$$PR = \frac{Y_f}{Y_r} \times 100. \quad (4)$$

F. System conversion losses: *LS*

The system losses LS are due to the conversion losses of the inverters (DC to AC) and are defined by the difference between the PV field efficiency (Y_a) and the final efficiency (Y_f):

$$LS = Y_a - Y_f. \quad (5)$$

G. Miscellaneous losses: *LC*

The miscellaneous losses LC are defined by the difference between the reference yield Y_r and the yield of the PV field Y_a. They represent the losses owing to the panel temperatures, wiring, partial shading, spectral losses, dirt, errors in finding the maximum power point, conversions (DC-AC) or others:

$$LC = Y_r - Y_a. \quad (6)$$

H. PV array efficiency: η_{PV}

The PV array efficiency is the ratio of the total energy generated by the PV arrays E_{DC} to the product of the amount of irradiance on the panel plane I_{POA} and the overall area of the PV array A:

$$\eta_{PV} = \frac{E_{DC}}{I_{POA} \times A} \times 100. \quad (7)$$

I. PV system efficiency: η_{sys}

The PV system efficiency is the ratio of the total energy generated by the PV system (E_{AC}) to the product of the amount of irradiance on the panel plane and the overall area A of the PV array:

$$\eta_{sys} = \frac{E_{AC}}{I_{POA} \times A} \times 100. \quad (8)$$

J. Photovoltaic inverter efficiency: η_{inv}

The inverter efficiency η_{inv} is the ratio of the total energy generated by the PV system to the total energy generated by the PV arrays:

$$\eta_{inv} = \frac{E_{AC}}{E_{DC}} \times 100. \quad (9)$$

K. Load Factor: *LF*

Finally, the load factor LF is defined as the ratio of the actual annual energy production to the amount of energy generated by the solar PV plant when operated at maximum rated power P_0 for 24 hours per day for one year:

$$LF = \frac{E_{AC}}{P_0 \times 24 \times 365} = \frac{Y_f}{8760} = \frac{Y_r \times PR}{8760}. \quad (10)$$

IV. PERFORMANCE ANALYSIS

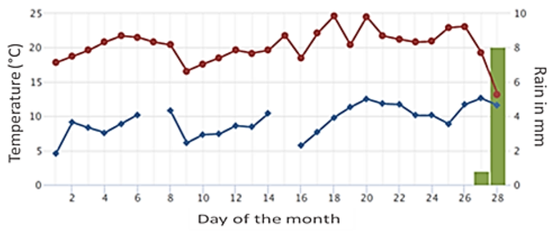
In order to analyze the performance of the 10 MWp grid-connected PV plant of Tozeur, the data collected from the SCADA system with a continuous run of 30 days, from January 20, 2022 to February 20, 2022 were used. These data were recorded with a one-minute step for the meteorological parameters (I_{POA}) and for the electrical production (E_{DC} and E_{AC}). The values were averaged over one day.

A. Climatic parameters

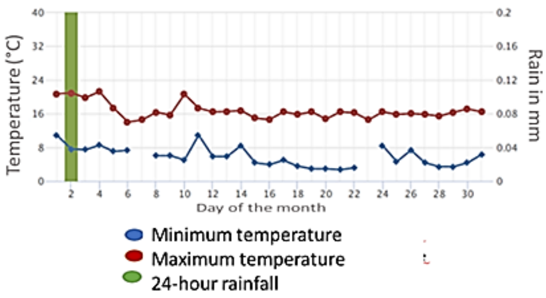
The minimal and maximal temperatures for each day for January and February 2022, are shown in figure 2 as captured on the monitoring screen. The values are comprised between 4°C and 25°C during these winter months. The average annual temperatures in Tozeur are around 22°C. January is usually the coldest month, with average minimum temperatures usually around 5°C. For comparison, July is the hottest month, with average maximum temperatures of 38°C. The temperature difference is very visible between the summer and the winter, and even more so between day and night, especially in the winter.

Tozeur has an arid climate. The rain came on for three days with a maximum of 40 mm. The average annual rainfall is generally between 75 and 100 mm, but the actual values vary considerably from year to year.

The average daily wind speed for the study period is given in figure 3. The minimal value is 14.5 $m.s^{-1}$ and the maximal one is 76.1 $m.s^{-1}$. The prevailing winds are East-West, with gusts in September and December. The sandy winds are frequent only in March.

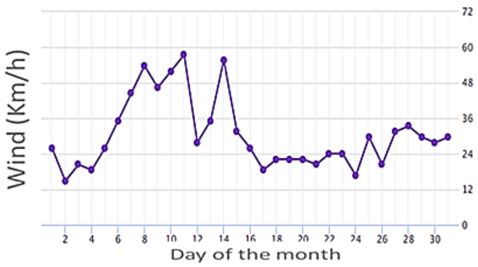


(a)

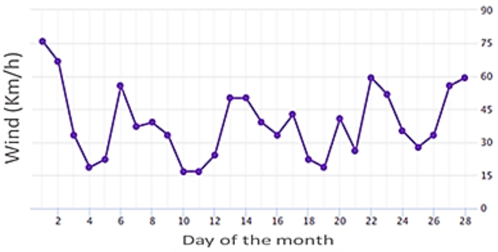


(b)

Fig. 2. Ambient temperature and rainfall at the Tozeur PV plant site during (a) January and (b) February 2022.

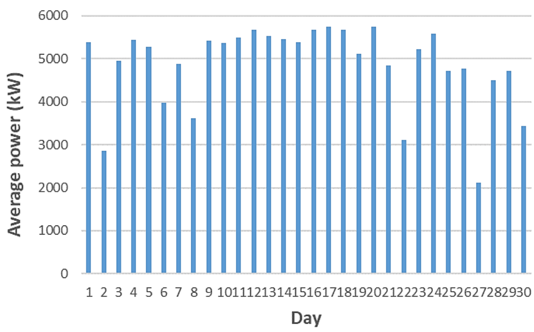


(a)



(b)

Fig. 3. Wind speed of the Tozeur PV plant site during the month of (a) January and (b) February.



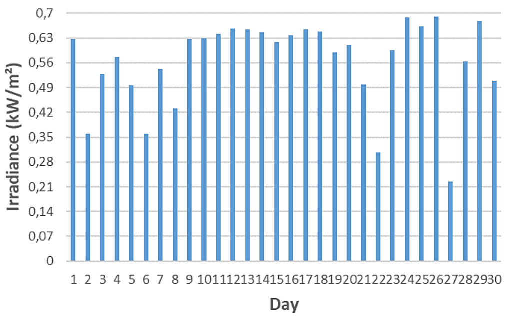


Fig. 4. Evolution of the average daily produced power and irradiance over the study period.

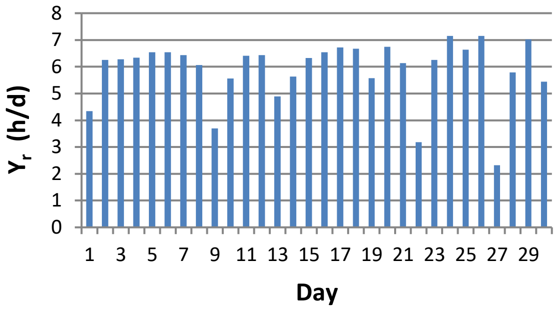


Fig. 5. Reference yield Y_r over the study period.

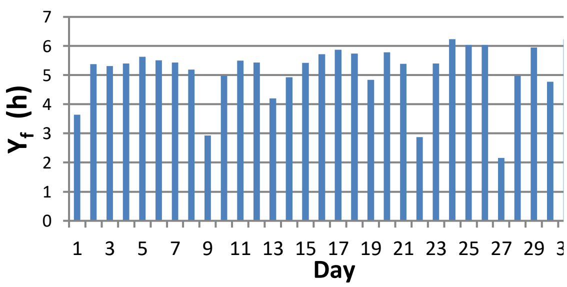


Fig. 6. Final yield Y_f over the study period.

B. Performance indicators

Figure 4 shows the variation of the power and of the irradiance for the study period. The produced power is proportional to the solar irradiance.

The variations of solar irradiance during the study period ranged from 0.22524 kWh/m² per day to 0.68926 kWh/m² per day. The daily average solar irradiance is 0.56500733 kW/m² per day. The variations of the power with time during the study period are between 2124.59178 kW and 5742.77492 kW. The average value of power is 4855.96495 kW per day.

Figure 5 represents the evolution of the reference yield. We can see that the values of Y_r are between 2.15 h/d and 7.15 h/d. The average monthly value of the reference yield is 5.9 h/d.

The average daily final yield Y_f of the PV system is given in figure 6. The final productivity varies between a minimum of 2.15 h/d for day 25 and a maximum of 6.23 h/for day 28. Days 1, 9, 22 and 27 have values slightly inferior to those of the other days as the irradiance is decreased respectively at 4.34, 3.69, 3.18 and 2.3 kWh/m². The average monthly value of Y_f is equal to 5.09 h/d.

The PR was determined on a daily basis for the 30-day continuous operation of the plant as represented in figure 7. The mean values were calculated for each day. The values of the PR are between 79.09 and 92.93% as displayed in figure 7. The maximum was reached on day 27 with a value of 92.93% and the minimum was recorded on day 9. The other days have a relatively stable performance index with a PR greater than 84%. For the given period the average PR value is 86.32%. A PR higher than 80% corresponds to a system whose performance approaches the ideal performance under STC conditions and a system with a PR lower than 70% should be suspected of failure or faults originating from the components (panels, inverters and so on) or from the installation conditions (nearby shading, excessive dusting of panels, etc.) [11]. For the case of this plant installed in Tozeur, this decline in performance ratio during day 9 was certainly due to the loss of production for 45 minutes because of the unavailability of the 33 kV network of the STEG. The lost energy was around 2723 kWh. The highest value of the performance ratio during day 27 can be explained by the moderate ambient temperature which did not exceed 20°C and by the gusty wind which favored the cooling of the photovoltaic panels, and consequently, improving the performance of the plant [9].

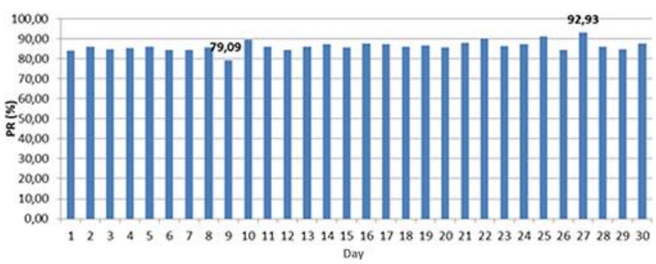


Fig. 7. Performance Ratio PR over the study period.

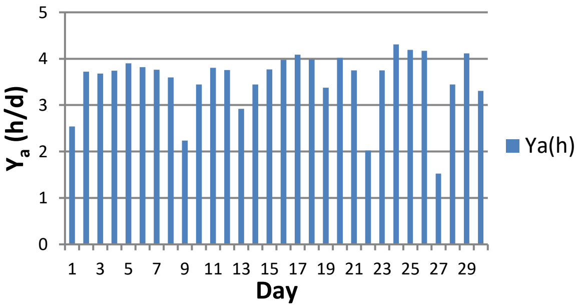


Fig. 8. Specific yield Y_a over the study period.

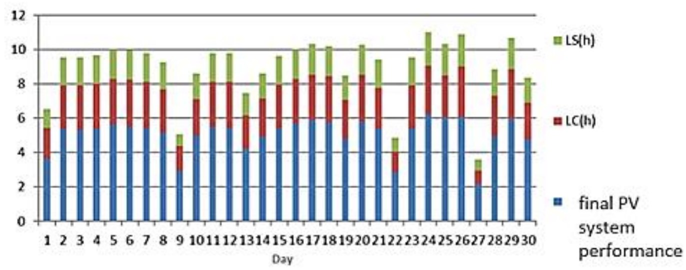


Fig. 9. Final yield Y_f superimposed with LS and LC losses.

The evolution of the specific yield over the study period is given by figure 8. It follows the same variations as the final yield Y_f provided in figure 6. Figure 9 shows the average final deliverable (Y_f), the system losses (LS) and the miscellaneous losses (LC) during the month of operation of the PV plant. Y_f, LS and LC are expressed in hours per day (h/d). As previously seen, the final efficiency varies with a minimum of 2.15h/d and a maximum of 6.23 h/d with a monthly average value of 4.19 h/d. Y_f is highly influenced by the variation of the solar irradiance. The LS losses of the system are relatively stable with an average of 0.37 h/d, ranging from a minimum of 0.63 h/d and a maximum of 1.92 h/d. The difference between the maximum and the minimum losses of the system is about 1.2 h/d. This shows that the PV system inverters were performing fairly well during the DC-AC conversion. The monthly miscellaneous losses are much more pronounced and range from 0.79 h/d to 2.98 h/d, with an average of 1.89 h/d. These losses are greater than 0.6 h/d for the study period of one month. They are known to be directly related to the losses due to the dusting of the photovoltaic panels and to the high module temperatures during the summer period.

The monthly energy generated by the photovoltaic system and the cumulative are shown in figure 10. The peak of the energy production was reached for day 24 with a value of 62.82 MWh and the minimum of energy was generated for day 27 with a value of 21.7 MWh. The maximum energy generated is 2.5 times higher than the minimum one. The average monthly energy production is 51.29 MWh. The total accumulated energy production for one month of operation is 1.54 GWh.

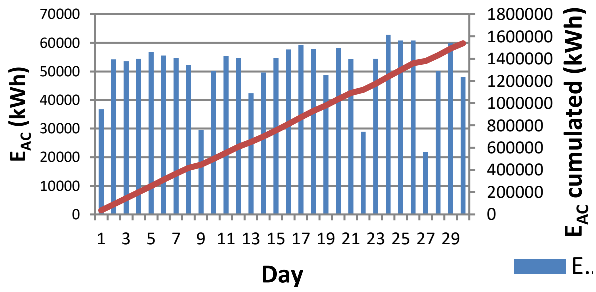


Fig. 10. Daily generated energy E_{AC} and cumulative energy over the study period.

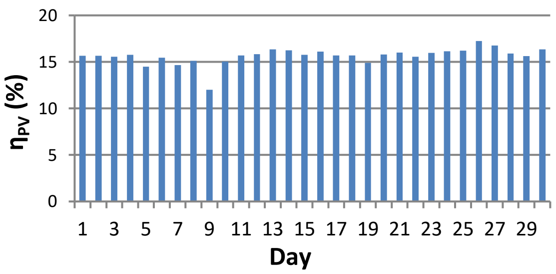


Fig. 11. PV field efficiency η_{PV} over time.

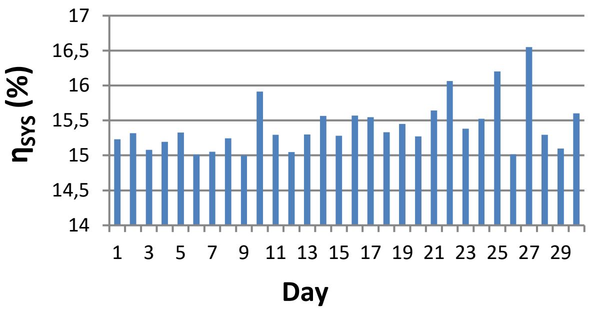


Fig. 12. PV system efficiency η_{inv} over the study period.

The efficiency of the photovoltaic solar panels varies depending on several factors, but generally, it remains between 12 and 20%. The output of a photovoltaic cell depends on the solar irradiance. From the results obtained from the evolution of the field efficiency η_{PV} depicted in figure 11, a minimum value equal to 12.05% and a maximum value equal to 17.3% respectively on days 9 and 26 were found. The average monthly value of the system efficiency is equal to 15.37%.

The efficiency of the system generally has values between 15% and 20%. Figure 12 displays the evolution of the system yield η_{sys} over the study period. The maximum value is equal to 16.55% and the minimum one to 15% on days 9 and 27 respectively. The monthly average value of the system efficiency is 15.37%.

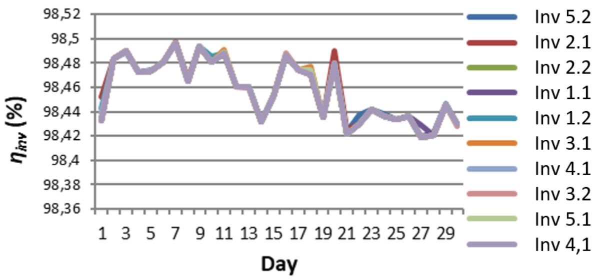


Fig. 13. Efficiency of the photovoltaic inverter η_{inv} over the study period.

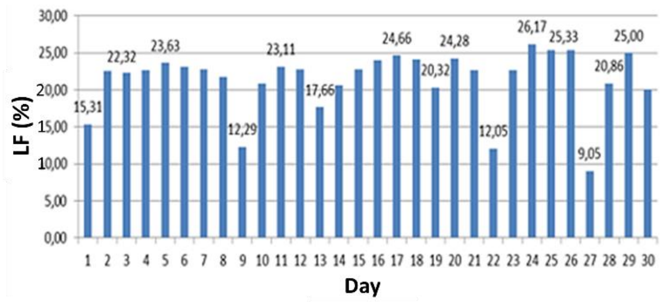


Fig. 14. Average daily load factor LF over the study period.

Figure 13 shows the efficiencies of the photovoltaic inverter η_{inv}. The efficiency, expressed in percentage, is the ratio of the output energy to the input energy. The values vary between a minimum of 98.41% and a maximum of 98.49% with a monthly average value equal to 98.45%.

The load factor LF varies from one generation unit to another, depending on the energy source (e.g. intermittent or not), the level of use of the production unit (e.g.: forced shutdown or limited production when the electricity demand is too low or in the case of maintenance) and also its location (e.g. sunshine in the area for solar panels, wind speed for wind turbines). The load factor of solar photovoltaic electricity is on average around 15% in France and 11.2% in 2020 for the UK [11,12]. This is significantly lower than the load factors of other renewable sources. This can be explained by the lack of consistency in the number of sunny days. According to figure 14, the daily load factor LF of the PV plant of Tozeur 2 from 20 January to 20 February 2022 changes between 9.05% and 26.17%. This change depends strongly on the daily energy produced and therefore on the available sunshine. The average value of the monthly load factor of the PV plant of Tozeur 2 is 21.37%. The lowest LF value was recorded on day 27 (9.05%). On the other hand, the highest LF value was recorded on day 24 (26.17%). The maximum value of LF was reached on day 24 with a maximum irradiance of 6.9 kWh/m^2. The minimum value of LF was observed on day 27 with a minimum irradiance of 2.15 kWh/m^2

TABLE II. SUMMARY OF THE PERFORMANCE PARAMETERS OF MULTIPLE GRID-CONNECTED PV SYSTEMS FOR DIFFERENT LOCATIONS.

Location	Climate	Capacity (kWp)	Daily Y_f (KWh/KWp)	PR%	Monitored period (month)	Reference
Kerman, Iran	Arid	—	—	80.81	12	[13]
Rafsanjan, Iran	Semi-arid	1.25	4.65	90	12	[14]
Oman, Sohar	Arid	3.2	5.14	84.6	12	[15]
Errachidia, Morocco	Arid	2.04	5.31	82.24	36	[7]
Tozeur, Tunisia	Arid	—	5.09	86.32	1	present work

V. PERFORMANCE COMPARISON

The performance indicators of the IEC61724 standard allow to compare photovoltaic systems independently of their location. In order to do so, the main performance indicators found here for the PV plant of Tozeur were confronted in table 2 to reported ones of PV plants also operating under arid climates. The average daily final yields Y_f are around 4 kWh/kWp. The performance ratio found of 86.32% is in agreement with the ones of the other studies between 80.81% and 90%, even though the performance ratios were determined for longer time intervals of at least one year. These ratios appear to be satisfactory for all the quoted studies. Nevertheless, these performances indicate that there is still room for improvement in order to get closer to the technical and theoretical limits. Particularly, the PV plants of Errachidia and Tozeur show very suitable results for crystalline silicon modules under desert environment. This specific environment is attractive for policymakers in Tunisia with several projects under preparation. In the project of the PV plant of Tozeur 2 the performance ratio was of 82.59%. The result found here is above this expected value.

VI. CONCLUSION

The performance of the 10 MWp grid-connected PV plant of Tozeur 2 was investigated. A detailed analysis was performed by using the monitored data over a period of 30 days in 2022 to determine the key indicators specified by the IEC 61724 standard summarized as follows:

- Monthly average baseline deliverability of 5.04 h/d, PV array deliverability of 2.04 h/d, and final deliverability of 4.19 h/d;
- The average monthly system losses and miscellaneous losses are 1.5 h/d and 2.36 h/d respectively. The relatively low value of system losses shows that the inverters are slightly impacted during power conversion;
- The average efficiency of the photovoltaic system is 86.32%, which is close to the ones of other photovoltaic installations operating in desert environments;
- The average efficiency of the rows and the PV system are respectively 12.05% and 17.3%, with an average value of 15.37%, with a variation between 15% and 16.55% for the PV system efficiency with a monthly average of 15.77%;
- The monthly efficiency of the inverter is equal to 98.45%.
- The load factor varies between 9.05% and 26.17%.

The Tozeur 2 PV plant has proven to provide excellent performance beyond expectations, and the evolution of the annual performance of the plant will have to be determined.

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REFERENCES

[1] L.M. Ayompe, A. Duffy, S.J. McCormack and M. Conlon, “Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland,” Energy Conversion and Management, vol. 52, pp. 816–825, 2011.

[2] M. S. Adaramola and E.E.T. Vågnes, “Preliminary assessment of a small-scale rooftop PV-grid tied in Norwegian climatic conditions,” Energy Conversion and Management, vol. 90, pp. 458–465, 2015.

[3] E. Kymakis, S. Kalykakis and T.M. Papazoglou, “Performance analysis of a grid connected photovoltaic park on the island of Crete,” Energy Conversion and Management, vol. 50, pp. 433–438, 2009.

[4] T. Khatib, K. Sopian and H.A. Kazem, “Actual performance and characteristic of a grid connected photovoltaic power system in the tropics: A short term evaluation,” Energy Conversion and Management, vol. 71, pp. 115–119, 2013.

[5] A. Al-Otaibi, A. Al-Qattan, F. Fairouz and A. Al-Mulla, “Performance evaluation of photovoltaic systems on Kuwaiti schools’rooftop,” Energy Conversion and Management, vol. 95, pp. 110–119, 2015.

[6] D. Okello, E.E. van Dyk, F.J. Vorster, “Analysis of measured and simulated performance data of a 3.2 kWp grid-connected PV system in Port Elizabeth, South Africa,” Energy Conversion and Management, vol. 100, pp. 10–15, 2015.

[7] A. Bouaichi, A. El Amrani, M. Ouhadou, A. Lfakir and C. Messaoudi, “In-situ performance and degradation of three different photovoltaic module technologies installed in arid climate of Morocco,” Energy, vol. 190, p. 116368, 2020.

[8] IEA-PVPS, Photovoltaic module energy yield measurements: Existing approaches and best practice, 2018.

[9] IEC61724-1:2017. Photovoltaic System Performance—Part 1:Monitoring. International Electrotechnical Commission, 2017. iTehStandards [WWW Document], n.d. URL. (accessed 20 10 20).

https://standards.iteh.ai/catalog/standards/sist/f8b04729-0bcc-498e-9541-57bc6463944f/sist-en-61724-2001

[10] A. Allouhi, R. Saadani, T. Kousksou, R. Saidur, A. Jamil and M. Rahmoune, “Grid-connected PV systems installed on institutional buildings: Technology comparison, energy analysis and economic performance,” Energy and buildings, vol.130, pp.188–201, 2016.

[11] J.B. Lee, J.W. Park, J.H. Yoon, N.C. Baek, and U.C. Shin, “An empirical study of performance characteristics of BIPV (Building Integrated Photovoltaic) system for the realization of zero energy building,” Energy, vol. 66, pp. 25-34, 2014.

[12] E. Elibol, Ö.T. Özmen, N. Tutkun and O. Köysal, “Outdoor performance analysis of different PV panel types,” Renew Sustain Energy Rev, vol. 67, pp. 651–661, 2017.

[13] S. Edalati, M. Ameri and M. Iranmanesh, “Comparative performance investigation of mono- and poly-crystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates,” Appl Energy, vol. 160, pp. 255–265, 2015.

[14] M. Mirzaei and M.Z. Mohiabadi, “A comparative analysis of long-term field test of monocrystalline and polycrystalline PV power generation in semi-arid climate conditions,” Energy Sustain Dev, vol. 38, pp. 93–101, 2017.

[15] H.A. Kazem, T. Khatib, K. Sopian and W. Elmenreich, “Performance and feasibility assessment of a 1.4 kW roof top grid-connected photovoltaic power system under desertic weather conditions,” Energy Build, vol. 82, pp. 123–129, 2014.