Journal of Advanced Research in Fluid
Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Effects of Temperature and Solar Radiation on Photovoltaic Modules Performances Installed in Oued Keberit Power Plant, Algeria

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ARTICLE INFO

Article history:
Received 4 September 2023
Received in revised form 22 November 2023
Accepted 1 December 2023
Available online 15 December 2023

Keywords:
Photovoltaic; PV plant; performance; efficiency; measured data

ABSTRACT

This study presents the measured data of the "Oued Keberit" PV plant over a period of four months (January to April 2022) after nearly 6 years of outdoor exposure to the climate of Souk Ahras, eastern Algeria, in order to evaluate the performance of the solar PV system. This evaluation includes the calculation of PV system performance variables such as module performance, final performance and performance of the module references, system losses, photovoltaic friendly efficiency, system efficiency, performance ratio and capacity factor based on measured data, allowing comparison of actual PV system performance and reference values determined by manifacturers. The results showed that the four-month average values of the parameters Eac, Yr, Yf, PR, η, CF are 1.06375125MWh, 4.08h, 4.25h, 1.06, 16.40%, 60.28% respectively. Also, the high efficiency of the photovoltaic system was obtained during winter, due to the low temperature and the sufficient amount of solar radiation. However, the photovoltaic system generates a lot of energy during summer, although there is less output than during the winter season. This is because summer has maximum values for sunshine duration and solar radiation.

1. Introduction

Due to climate change caused by carbon dioxide emissions, solar-powered electricity generation has attracted increasing attention because it is clean, sustainable and plentiful. Also, it can be used in remote regions either directly in thermal form (photothermal) or in electrical form (photovoltaic (PV)) [1,2]. A large-scale photovoltaic plant has been built all over the world, and the long-term stability of their power generation capacity is becoming more important [3]. Predicting the exact level of electricity production during the lifetime of PV modules is the key factor in the PV industry [4,5]. However, the information provided by the manufacturers only allows an approximate sizing of the PV system. One of the major problems with PV systems is the degradation of PV modules when exposed to natural outdoor conditions [6-8]. PV module degradation is highly dependent on

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https://doi.org/10.37934/arfmts.112.1.204216

climate, but also on harsh environmental parameters, PV technology, exposure period, installation method, solar tracking system, solar radiation concentration mechanism, and the PV system voltage [9].

Quansah and Adaramola [10] present the results of field studies on the Performance degradation of 22 monocrystalline silicon modules installed for 16 years in three communities in northern Ghana. The results obtained showed that the maximum power of the modules (Pmax) decreased by 18.2 at first, then it further decreased up to 38.8% (median - 24.6%), which translates into an annual linear degradation rate of 1.54%. PV module output power losses are dominated by short-circuit current (Isc) and fill factor (FF) losses, which are 0.75%/year and 0.54%/year, respectively (median values). Encapsulate discoloration and junction box adhesive degradation were the most common visually observable defects on PV modules. Hossion [1] visited several rooftop solar power plant sites in Dhaka (Bangladesh), which are at least five years old after their installation. He did a visual inspection study of solar panels installed on a roof to examine their visual degradation. This degradation may have caused their exposure to the environment and their aging. Next, he measured Current-Voltage characteristics under sunlight using a Seaward I-V PV-200 handheld plotter. Current voltage data was analyzed using the Seaward Solar Chart data analysis tool. The tool was used to plot current-voltage and voltage-voltage curves. From the data analysis, he was able to estimate the standard test case (STC) strength, fill factor (FF) and efficiency of the selected PV modules, to have a clear view of the test of rooftop solar PV modules in Dhaka city.

de Oliveira *et al.,* [11] examined and compared the performance losses and degradation mechanisms of the modules of two PV systems installed in the state of Minas Gerais, Brazil, for periods of approximately 15 years. Visual inspections of the two PV module sets concluded that one module source (SET A) had virtually no encapsulant discoloration and little indication of delamination and corrosion. In contrast, the other module source (SET B) exhibited significant yellowing/browning, extensive areas of delamination, and fairly extensive interconnect corrosion. The measured changes of the two modules in the electrical characteristics were: SET A having an average annual power loss of 0.4 to 0.5%, and SET B with 2.3 to 3.7%/year over their installation time. Discoloration and delamination of the encapsulant provided the first clues to measure differences in performance of PV modules that are exposed to prevailing weather conditions, high ultraviolet (UV) radiation and high ambient temperatures. Clavijo-Blanco *et al.,* [12] studied and analyzed the results of several laboratory tests on a sample of a photovoltaic power plant with a nominal power of 2.85 MW in service for 11 years and whose photovoltaic modules come from different manufacturers and classes. The tests performed on each sample were detailed visual inspections for power rating, electroluminescence (EL), and electrical insulation.

The tested PV modules were analyzed and evaluated according to an established acceptance/rejection criterion set by their laboratory in compliance with the standards of the International Electrotechnical Commission, bibliographical contributions and PV module warranty conditions. Taking into account the age of the factory and the criteria established in the nominal power, 80.01% of the modules of the sample were in good condition, 10.27% degraded and 9.72% rejected. Taking into account the pre-established criteria for nominal power, 80.01% of the modules examined were in good condition, 10.27% degraded and 9.72% rejected. The results also showed that the total average annual degradation rate of the photovoltaic plant after 11 years of operation is 0.94%/year. PV module degradation studies are usually based on accelerated tests or field tests, which are time-consuming and labor-intensive. Huang and Wang [13] studied the degradation process of PV modules by simulation. They took a circuit-based model that is used to describe photovoltaic characteristics to environmental conditions and aging factors of photovoltaic modules.

The analysis they did on each ageing factor shows that the decrease in short-circuit current (the main reason for power loss) is mainly caused by optical degradation. The decrease in fill factor is mainly due to the degradation of parasitic resistances, worsening the output power. Statistical analysis of photovoltaic characteristic parameters based on many photovoltaic modules with the same technology, indicated that the degradation process could be very complicated depending on the degradation patterns of ageing factors. The objective of the work of Ndiaye *et al.,* [14] was to understand the different degradation modes of PV modules and the associated factors. The study presents a measurement platform dedicated to a study related to the degradation of the electrical characteristics of photovoltaic modules. It is installed on the site of the University of Dakar in Senegal. The authors proposed a method for normalizing the direct measurements of the short-circuit current (Isc) and the open-circuit voltage (Voc) of PV modules. The approach used for the evaluation of the degradation of Isc and Voc involved a comparison between the reference values given by the manufacturer and those measured in real operating conditions brought back to the standard test conditions (STC). The results presented on the degradation of Isc and Voc photovoltaic modules cover the first ten months of measurements from March to January. The short-circuit current degradation is about 13% for the three days. The degradation of the open circuit voltage measured during the three days is 8%.

Kahoul *et al.,* [15] analyzed the degradation of the electrical performance of PV modules (UDTS-50) operating for a period of 11 years in a region of the Sahara (URER-MS Adrar). It is an experimental study of the current-voltage characteristics of several PV modules exposed to extreme climatic conditions in a desert area. The degradation and failure modes of electrical performance are estimated from a series of current-voltage characteristics carried out in the field. Experimental results have shown that some PV modules degrade up to 12% compared to their initial state. In the same context of previous literature, we try to approach one of the most important PV plants in Algeria, namely the power plant of Oued Keberit in Souk Ahras (longitude 7°52'E, latitude 35°55'N). During the first part, we present a summary of the induction of the PV plant and, during the second, we study the evolution of degradation of the PV modules of the plant.

2. Location

2.1 Site

The Oued Keberit photovoltaic power plant (Figure 1) is located on the top of a hill, about 70 km south-west of Souk Ahras, a province in the north-east of Algeria, with an area of 30 hectares. The geographical coordinates of the site are 35°55’N and 7°52’E.

Fig. 1. Site satellite photo

2.2 Climatic Conditions

Meteorological parameters such as solar irradiation, ambient temperature, wind speed and relative humidity have an impact on the performance of photovoltaic systems. These parameters are essential for correctly evaluating the performance of the PV system.

The monthly average values of these climatic parameters, presented in Table 1, relating to the site of the Oued Keberit photovoltaic power plant are very favorable for any photovoltaic power plant project [16].

Table 1
Mean values of meteorological parameters

Year	Month	Solar radiation (W/m^2)	Temperature (°C)	Humidity (%)	Wind speed (m/s)
2022	Janvier	253.73	9.11	41.73633	3.680514
	Février	315.02	11.87	37.17627	3.815425
	Mars	339.08	12.97	35.05626	3.567341
	Avril	465.84	16.39	29.35119	4.32222

3. Details of PV Plant

3.1 PV Array and Plant

The plant was commissioned on April 24, 2016. It produces 30kV in the grid, with a power of 15MW. The plant consists of 60060 photovoltaic modules, of 250W, made of polycrystalline silicon by Yingli. This plant is designed in 15 sub-fields, and each sub-field consists of 4044 PV modules with an installed capacity of 1,001 MWp. Each subfield is equipped with two TBEA brand central inverters and a step-up transformer.

3.1.1 Detailed information on PV modules

Detailed information on PV modules is shown in Table 2.

Table 2
Main Parameters of PV Modules

Technology	Module PV
Measured power (W)	250±5
I_{sc} (A)	8.92
V_{oc} (V)	37.6
VMP (V)	29.8
IMP (A)	8.39
Number of cells in a PV module	60
PV module area (m^2)	1.62
Form Factor (%)	74
Yield (%)	16.40

3.1.2 Installation operating principle

The modules are connected in series to form a string to increase the voltage, and these strings are connected in parallel to a junction box to increase the current.

Low voltage is produced at distribution substations (inverters/step-up transformers) where direct current is converted to alternating current (inverter role) and brought up to the required voltage (transformer role). The energy is collected from the distribution substations to the delivery structure, then it is metered and injected into the public distribution grid.

3.1.3 Effective peak power of the PV array

As shown in Table 3, the monthly energy production varied from 135399.7 MWh (January 2022) to 1450386 MWh (April 2022). It is also noted that the energy remains almost constant with a value of 1482.321 MWh. It can be analyzed that the power generation capacity in the photovoltaic system was found to be higher during the month of April than the rest of the months.

Table 3
Average PV module energy

Parameters	January	February	Mach	April
Energy produced (MWh)	135399.7	137067.8	138080.1	140386
Energy consumed (MWh)	1450.791	1472.43	1487.808	1518.256

Figure 2 and Figure 3 represent the variations of current and power of PV cells as a function of voltage.

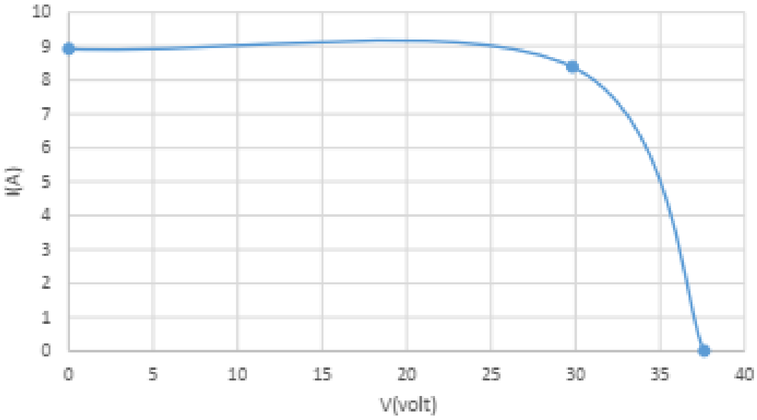

Fig. 2. I-V characteristic of PV cells

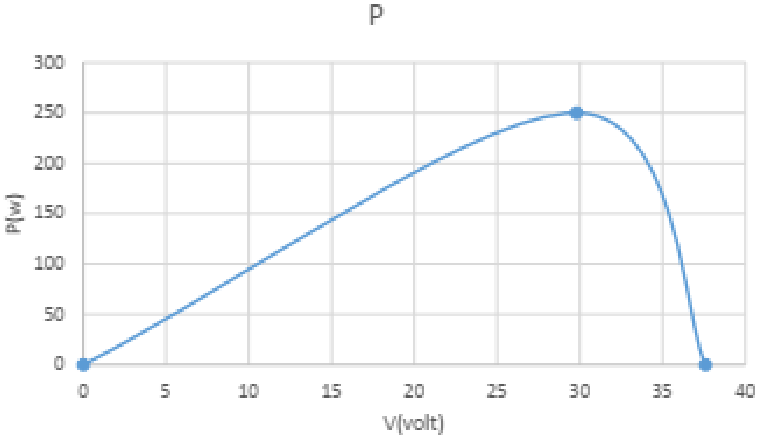

Fig. 3. P-V characteristic of PV cells

4. Performance Evaluation of the PV Modules

The performance of a PV system depends on its geographical location, solar radiation, energy efficiency and system losses. The main parameters for evaluating PV system performance are listed in Table 4.

Table 4
Main parameters for evaluating PV system performance

Parameters	Expression	Physical Meaning
Module performance (string) [17]	$Y_A = \frac{E_{DC}(KWh)}{P_{mp;rated}(KW)}$	Represents the number of hours taken by the PV system to produce the reference DC power
Module final performance [18]	$Y_f = \frac{E_{AC}(KWh)}{P_{mp;rated}(KW)}$	Represents the number of hours of operation of the PV array at its nominal power to supply the same energy
Module reference performance [17]	$Y_r = \frac{H(KWh/m^2)}{G_{STC}(KW/m^2)}$	Represents the number of hours required to receive the reference irradiation (Solar irradiation under standard conditions).
Performance report [19]	$PR = \frac{Y_f}{Y_r}$	Indicates the overall effect of losses on the production of modules in a PV system. Also indicates how close a PV system is to ideal performance under actual operating conditions.
Capacity factor [17]	$CF = \frac{Y_{f.m}\left(\frac{h}{d}\right)}{24 * number\ of\ days\ un\ month} * 100\%$	Represents the actual electricity production compared to the maximum possible electricity production capacity of a power plant.
Yield η [19,20]	$n_{sys}(\%) = \frac{E_{ac}(kWh)}{H\left(\frac{KWh}{m^2}\right) * A(m^2)} * 100\%$	Represents the total energy generated by the PV modules compared to the solar energy received by the global surface of these modules
Module losses (Lc) [18]	$L_c = Y_r - Y_a$	Lc is due to thermal capture loss
System losses (Ls) [21]	$L_S = Y_a$ - Y_f	Shows discontinuous inverter operation and passive circuit element losses

Table 5 shows the mean quantitative values of the performance variables. The values of these variables show a decreasing trend over the last four months.

Table 5
Mean values of performance parameters

Parameters	January	February	Mars	April	Average Value
Eac (kWh)	0,980161	1,072828	0,980161	1,221855	1,06375125
Yr	2,890287	3,707739	4,0137	5,719367	4,08277325
Yf	3,920645	4,291313	3,920645	4,88742	4,25500575
PR	1,302716	1,13628	0,954786	0,857636	1,0628545
η (%)	20,10364	17,53518	14,73435	13,23512	16,4020725
CF (%)	56,6968	63,8588	52,6968	67,8808	60,2833

5. Results and Discussion

5.1 Figure Style and Format

The PV panel temperature is monitored every day for four months: January, February, March and April. Indeed, the panel temperature evolution during the month of January is represented, as shown in Figure 4, and this variation is between two extremes, 4.65°C and 15.96°C. Whereas Figure 5 represents the PV panel temperature variation in February between two extreme values which are more important than those of January, 6.89°C and 17.22°C. As it is also important to point out that there was some instability during this month of February. For the month of March, the temperature extremes are 6.23°C and 18.58°C (Figure 6). While those for the month of April are 9.51°C and 22.42°C (Figure 7).

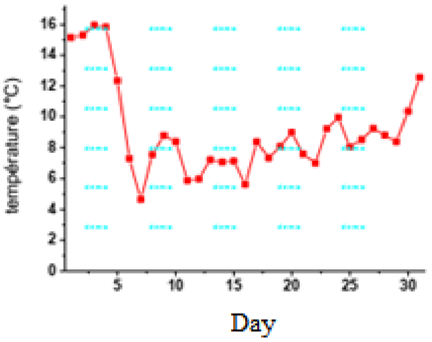

Fig. 4. Temperature variations in January

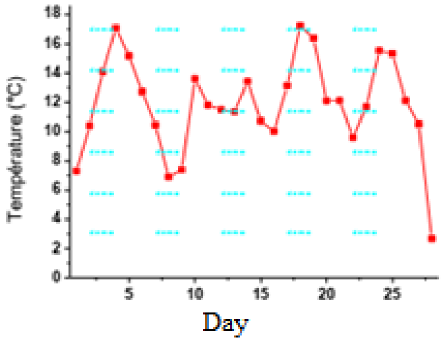

Fig. 5. Temperature variations in February

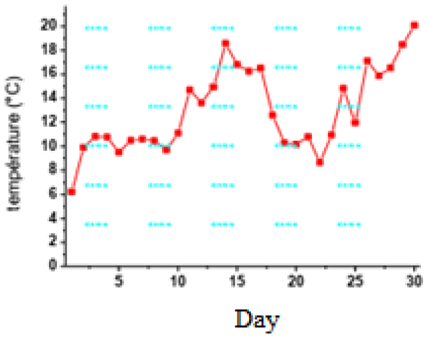

Fig. 6. Temperature variations in March

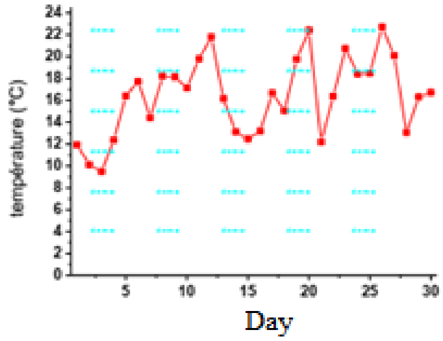

Fig. 7. Temperature variations in April

5.2 Figure Style and Format

The PV panel temperature varies proportionally depending on the months, January, February, March and April, as shown in Figure 8. It increases from 9.11ºC in January, 11.87ºC in February, 12.97ºC in March and 16.39ºC in April.

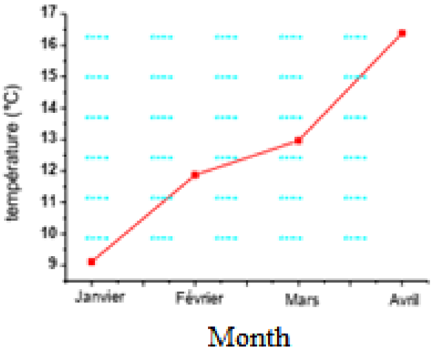

Fig. 8. Temperature variations depending on the month

5.3 Variations in Solar Radiation Depending on the Month

Figure 9 through Figure 12 show the variations of solar radiation during the months January, February, March and April. For the month of January, solar radiation decreases to a minimum value of 30.87W/m^2 during the tenth day, then it rises to a maximum value at the end of the month. It varies between 453 and 48.03W/m^2 in January. For the month of February, solar irradiation dropped to an average of 315.02W/m^2, 339.08W/m^2 in March, 465.84W/m^2 in April.

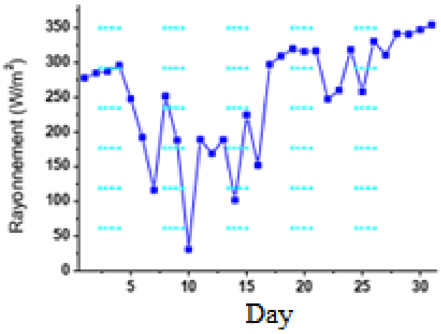

Fig. 9. January solar radiation variations

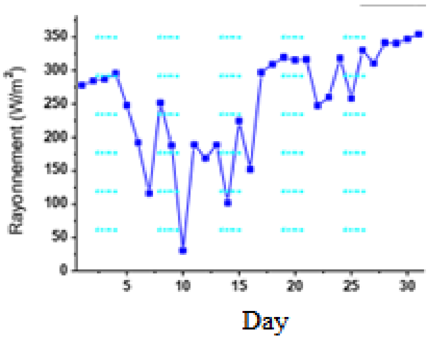

Fig. 10. February solar radiation variations

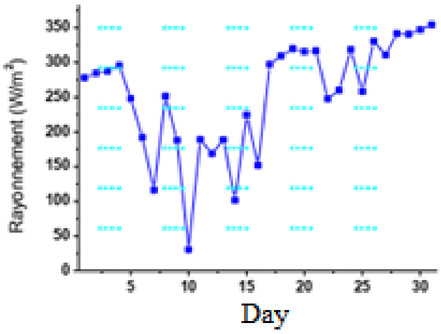

Fig. 11. March solar radiation variations

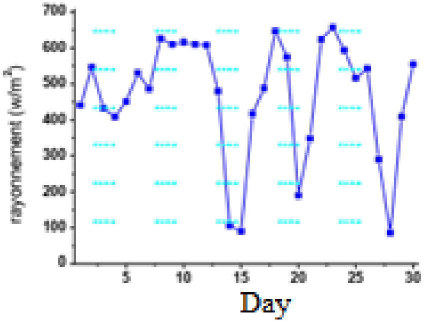

Fig. 12. April solar radiation variations

The increase in solar irradiation falling on the photovoltaic modules is accompanied by an increase in their temperature. The increase is from 253.73W/m^2 in January, 315.02W/m^2 in February, and 339.08W/m^2 in March to 485.84W/m^2 in April, as shown in Figure 13.

The increase in the temperature of the PV panels and the solar irradiation during these 4 months of monitoring explains a gradual increase in the energy produced by these panels, where 135399.7MWh was recorded in January and 140386MWh in April.

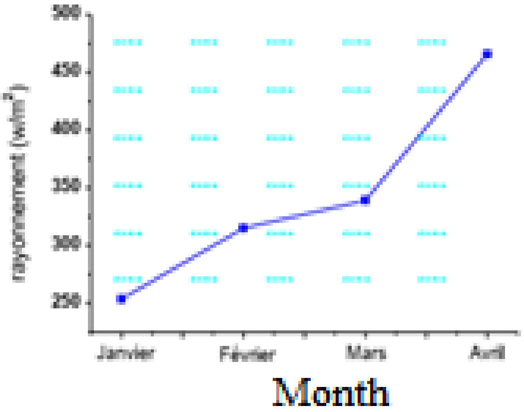

Fig. 13. Radiation variations depending on month

5.4 Module Performance Variations by Month

The monthly average, minimum, and maximum module performance values (Figure 14) were set at 4.38 hours, 4.04 hours (January 2022), and 5.03 hours (April 2022), respectively. The final performance reflects the energy production capacity of the solar plant. It is noted that Yf varies between 3.9h and 4.9h during the monitoring period, and the highest value is in April at 4.9h (Figure 15).

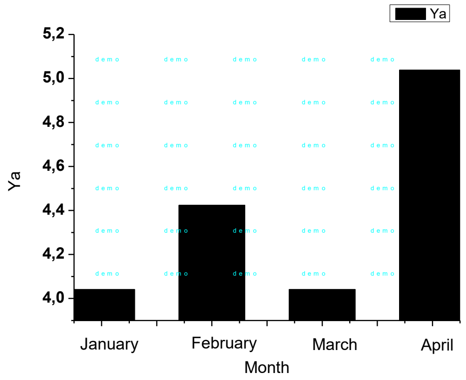

Fig. 14. Module performance variations by month

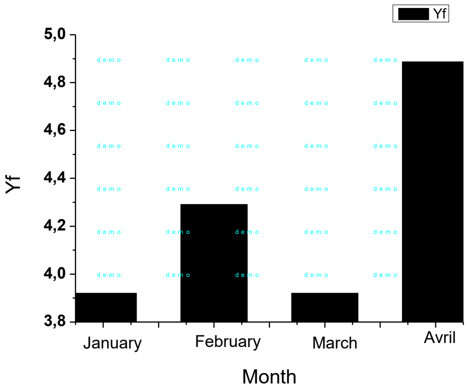

Fig. 15. Final module performance variations by month

5.5 Module Benchmark Performance Variations by Month

The monthly average, minimum, and maximum benchmark performance values (Figure 16) were set at 4.25 hours, 3.92 hours (January 2022), and 4.88 hours (April 2022), respectively. The values of the performance ratio (PR) over 4 months are recorded and presented in Figure 17. They decreased from 1.30 in January, 1.13 in February, 0.95 in March and 0.85 in April.

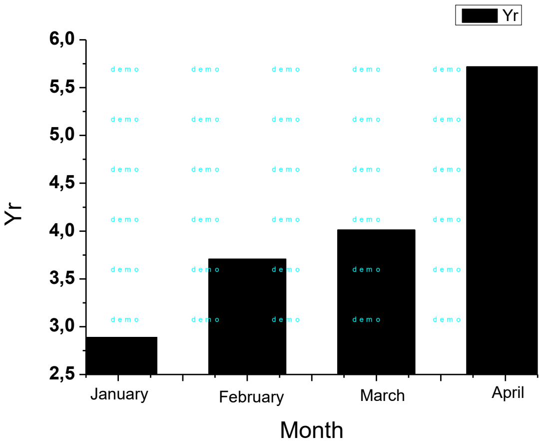

Fig. 16. Variations in module benchmark performance by month

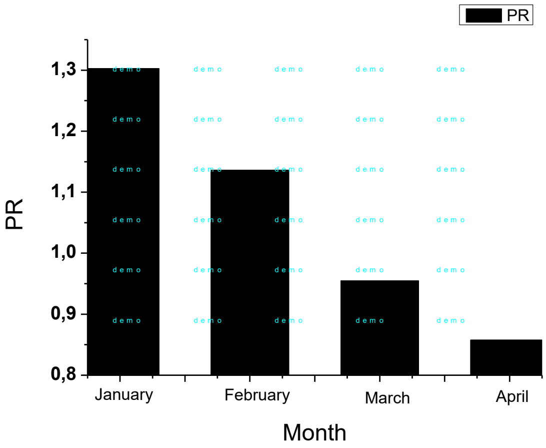

Fig. 17. Performance ratio (PR) variations by month

5.6 Capacity Factor (CF) Variations according to Month

The capacity factor is also one of the most important factors to remember when analyzing the performance of photovoltaic PV systems. The CF average in January is 52.6%, 63.8% in February, 52.6% in March and 67.8% in April (Figure 18).

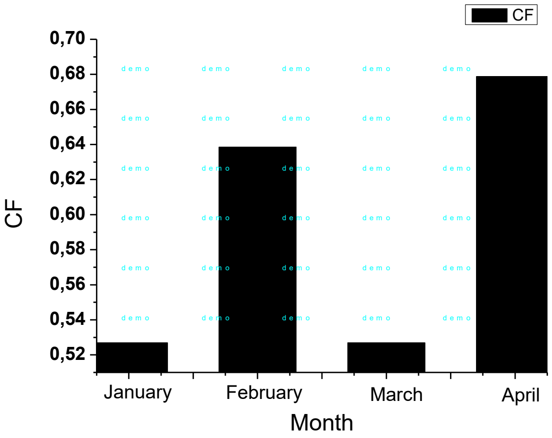

Fig. 18. Capacity Factor (CF) variations depending on the month

5.7 Yield Variations by Month

As the yield is the most important factor to remember for the analysis of the performance of photovoltaic systems. The yield during the month of January increases as shown by the curve Figure 19 according to a linear function. Figure 20 to Figure 22 show that the yield continues to decrease in February, March and April.

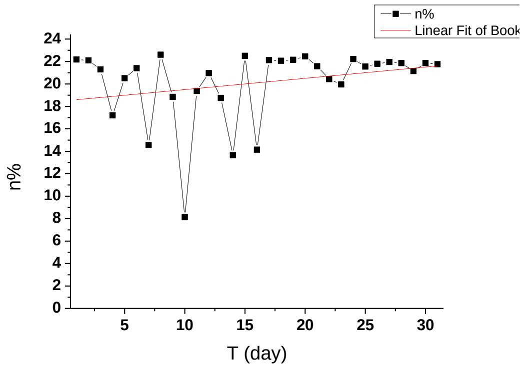

Fig. 19. Yield variations in January

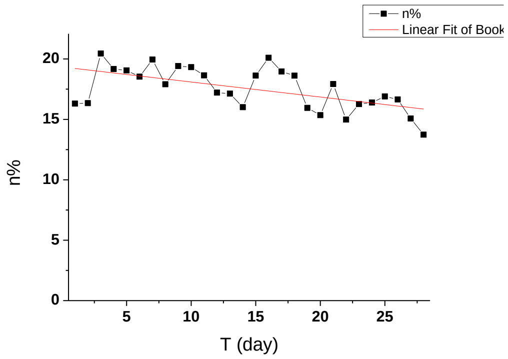

Fig. 20. Yield variations in February

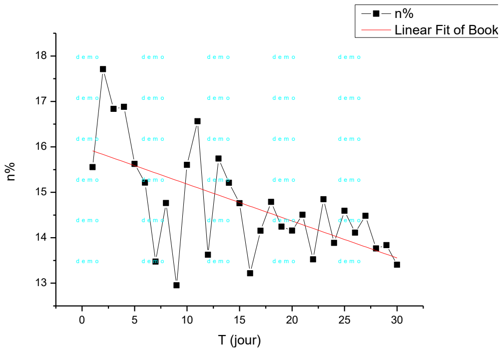

Fig. 21. Yield variations in March

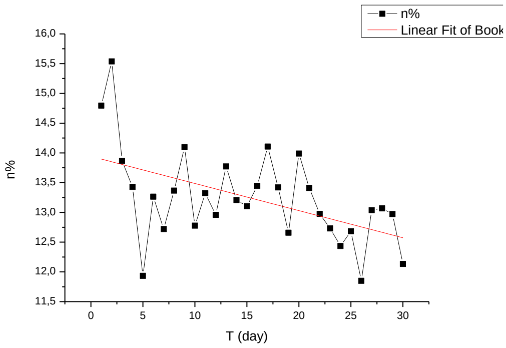

Fig. 22. Yield variations in April

Figure 23 represents the panel's yield evolution according to the months of monitoring. Indeed, we recorded a yield value of 20.1% in January, 17.5% in February, 14.7% in March and 13.2% in April. This decrease is due to the temperature rise of the PV panels and the insufficient amount of solar radiation. However, the PV system generates a lot of energy during summer, despite having a lower yield than in the winter season. This is due to the fact that summer has maximum values for sunshine duration and solar radiation.

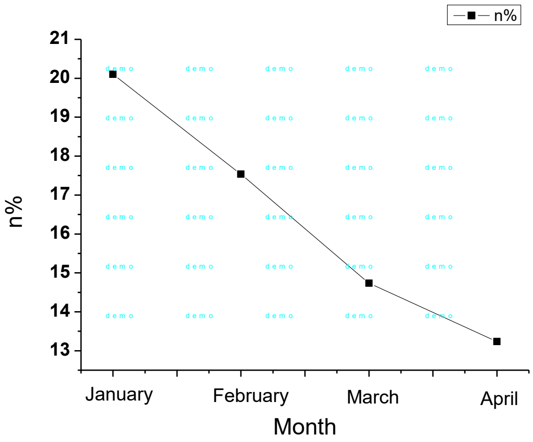

Fig. 23. Yield variations by month

5.8 Variations in Energy Losses Depending on the Month

Figure 24 and Figure 25 represent the average monthly PV panel losses (Lc) in the 4 months, January, February, March and April. It is noted that the energy losses during the first two months are non-existent and then begin to increase in March and April, where losses have been recorded over time. These losses are due to the transfer of heat between the PV panels and their environment and consequently, a decrease in yield. System losses (Ls) of 0.121h in January, 0.132h in February, 0.119h in March and 0.151h in April were recorded.

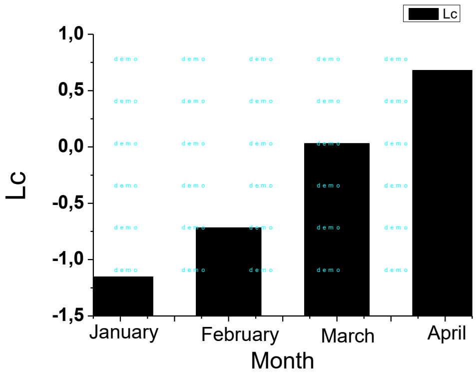

Fig. 24. Variations in module losses (Lc) according to month

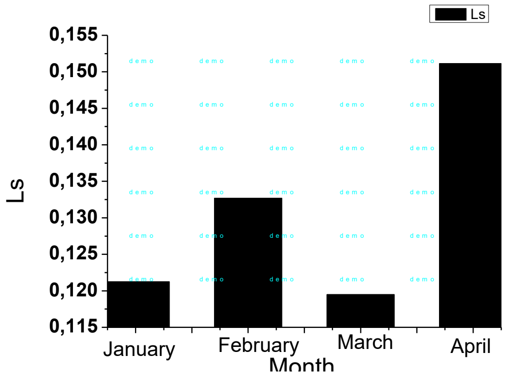

Fig. 25. Variations in system losses (Ls) according to month

6. Conclusion

This paper presents one of the most important photovoltaic plants in Algeria "Oued Keberit" in order to evaluate the performance of the photovoltaic solar systems which make up this PV plant on the basis of the data actually measured, and to show the correspondence between the reference values determined by the manufacturers and actual measurements. Analysis of the real data enables you to underline the following conclusions:

i. The PV panel temperature varies from month to month. It goes from 9.11 ºC in January, 11.87 ºC in February, 12.97 ºC in March and 16.39 ºC in April. Its increase is proportional to the increase in solar radiation.
ii. The increase in solar radiation during these four-months of monitoring explains a gradual increase in the energy produced by these panels where 135399.7 MWh was recorded in January and 140386 MWh in April.
iii. The photovoltaic system generates a lot of energy during summer, although productivity is lower compared to winter. This is because the summer season has maximum values for sunshine duration and solar radiation.

The four-month average values of the parameters Eac, Yr, Yf, PR, η, CF are 1.06375125MWh, 4.08h, 4.25h, 1.06, 16.40%, 60.28% respectively.

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