Case study

Experimental evaluation of the performance degradation of a solar PV plant operating in a Sahelian climate

.

ABSTRACT

ABSTRACT: Niger, the Sahel country, is known for its extreme climatic conditions and with a low electrification rate. To increase its electricity production, the first large-scale solar power plant was installed and connected to the national grid. This power plant is located in the Malbaza department in the Tahoua region (13°58.54 N and 13°58.54 E). It has a capacity of 7 MW and is composed of photovoltaic solar panels of monocrystalline technology. In this study, we propose a method for analysing the degradation of a PV solar power plant under its operating conditions. For this study, we use annual energy production data, recorded on the site, from 2019 to 2021. The method is based on the performance ratio values measured during these three years of operation. An hourly I_R energy generation index was introduced to study the degradation and reliability of the system. The performance ratio values obtained by the measurements in 2019, 2020 and 2021 are 73.22, 72.73 and 70.84 respectively; the hourly energy generation index values calculated are 0.921, 0.914 and 0.891 respectively. We also calculated the performance ratio value from the PVsyst database.The value obtained is 79.50%. Thus, a degradation of 1% per year is estimated over the three years of operation. In the end, a comparison was made with other studies.

Keywords: Performance ratio, degradation rate, monocrystalline technology, energy generation index.

1. INTRODUCTION

Niger, a vast landlocked country in the Sahel, has an important solar resource. The average insolation time is 8.5 hours/day and the average power received is between 5 and 7 kW/m²/day [1]. Thus, to improve the country's energy production, the Nigerien authorities have thought of developing solar photovoltaic power plants. In 2018, a first 7MW solar photovoltaic plant was built by the State of Niger, in the town of Malbaza. However, forecasting the production of electricity from PV systems is a complex task[2]. It takes into account the impact of weather conditions and the effect of degradation of PV system performance. This degradation is most often due to shadows, temperature, dust and defects in the system components. A degraded PV system loses its performance over time. This paper investigates the degradation of this plant after three years of operation. A collection of actual measurement data from the site was carried out over a three-year period: 2019, 2020 and 2021. The theoretical model was implemented using PVsyst software. Several studies have shown that this software gives a good estimation of meteorological and electrical data [3], [4].

2. MATERIAL AND METHODS

The present study is based on measurements of the solar PV plant, located in Malbaza, in the Tahoua region of Niger (13°58',54 N and 13°58',54 E). The data was collected over a three-year period from 2019 to 2021. Tables 1 and 2 show the characteristics of the plant and its components. An integrated data acquisition system monitors the main parameters of the PV system. Data is recorded every minute by a SCADA system.

Table 1. Characteristics of the inverters and PV panels used.

Inverter specification	Value	PV Module Specifications	Value
Max Power DC	1200 kW	Rated power at STC	330 Wp
Max Input Voltage	1100 V	Module efficiency	17.07 %
MPP voltage range	600–850V	Max voltage (Vmpp)	36 V
Max Input Current	1710 A	Max current (Impp)	9.17 A
AC Power Range	1000 kW	Open circuit voltage (Voc)	45.6 V
Rated AC voltage range	160–280 V	Open circuit current (Isc)	9.65 A
Frequency	50 HZ	NOCT	46 ±˚C
Max output current	1732 A	Temperature coefficient at Pmax	−0.3845 %/˚C
Max. frequency	98.30%	Temperature coefficient at Voc	−0.2941 %/˚C
Weight	61 kg	Temperature coefficient at Isc	0.0681 %/˚C

Table 2.Characteristics of the Malbaza PV plant.

N°	Parameter	Value
1	Rated power at STC	7MW
2	Number of PV modules	21231
3	Number of inverters	7
4	Number of modules/strings	42
5	Number of strings	1011
6	Number of strings/inverters	144
7	Output voltage	3 phases 415V AC

In order to evaluate the degradation of this system, a method based on the values of performance ratios was used. It consists in determining the energy generation index I_R, defined as the ratio between the actual values of the output performance ratios and the expected values of these same performance ratios, at the output. This index is calculated from formula (1) :

$$I_R = \frac{PR\ réel}{PR\ similé} \quad (1)$$

This index is used to quantify the degradation and assess the reliability of the PV system.

In the present study, the theoretical model was simulated under the PVsyst software. A high I_R index indicates a good agreement between the actual performance ratio value and the measured one. It can therefore be stated that the PV system has a high reliability, when the actual and theoretical values are very close. A low I_R index means that the actual ratio value is lower than the theoretical ratio value due to performance losses caused by shading effects, temperature, failure or partial or total failure.
Matlab software was used to obtain the correlation curves and Excel software was used for comparisons.

3. RESULTS AND DISCUSSION

The PVsyst software was used to monitor the meteorological data and then resample it to obtain hourly meteorological data. The analysis was performed on filtered data, without including the records available during the night.
Figure 1 shows the evolution of the performance ratio (PR) of the plant in the years 2019, 2020 and 2021 and the one estimated from PVsyst. A decrease in performance over the years indicates a degradation of the system. Thus, it can be observed that, apart from the month of September 2020, the monthly averages of the performance ratios measured over the three collection years are low compared to the estimated monthly values. The lowest value of the ratios is observed in May 2019, with an average of 52.55% and the highest is 84.47%, observed in September 2020.

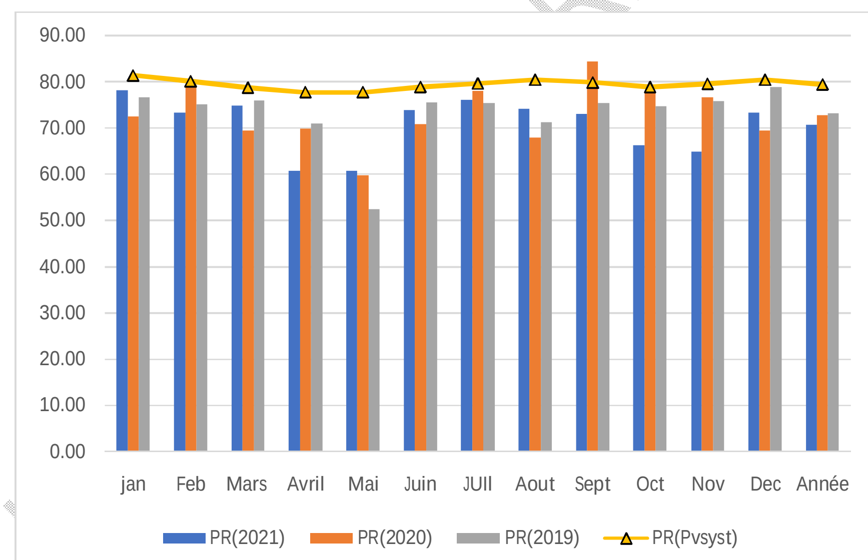

Fig. 1. Simulated and measured PR of the years 2019, 2020 and 2021.

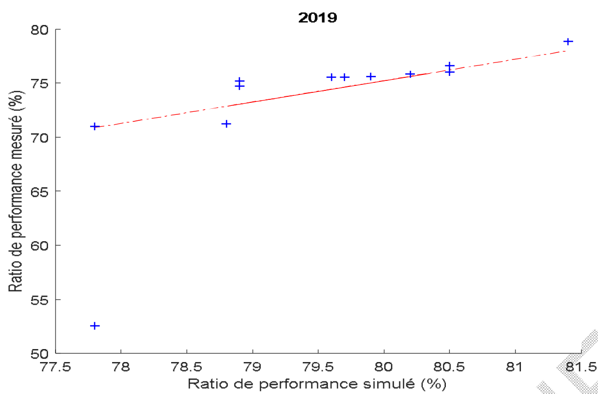

Fig. 2. Correlation between measured and simulated PR for the year 2019,*$R^2=0.34$*

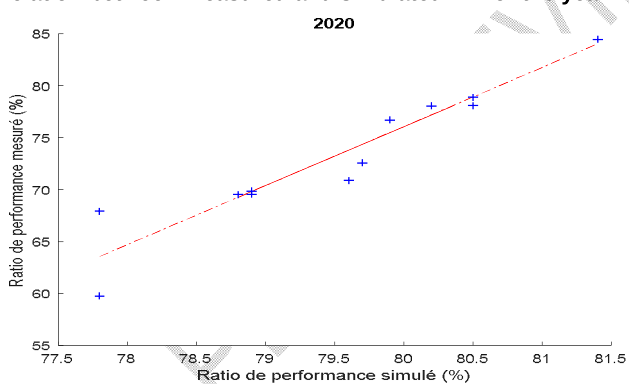

Fig. 2. Correlation between measured and simulated PR for the year 2020,*$R^2=0.14$*

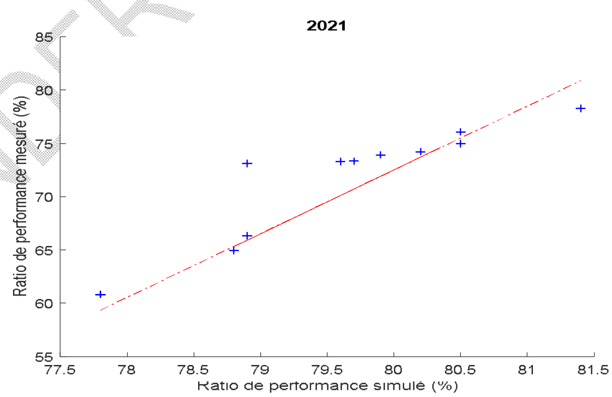

Fig. 4. Correlation between measured and simulated PR for the year 2021, *$R^2=0.58$***.**

Figures 2, 3 and 4 ~~below~~ show the correlations between the values of the performance ratios obtained from the measurements and those obtained from the PVsyst data. The correlation coefficient R^2 has been calculated for each case. This is one of the most commonly used coefficients. It measures the linear relationship between two variables. Its value varies from 0.14 to 0.58 over the years. The high coefficients show that the actual ratio is very close to the predicted ratio, which would demonstrate that the PV system is working well.

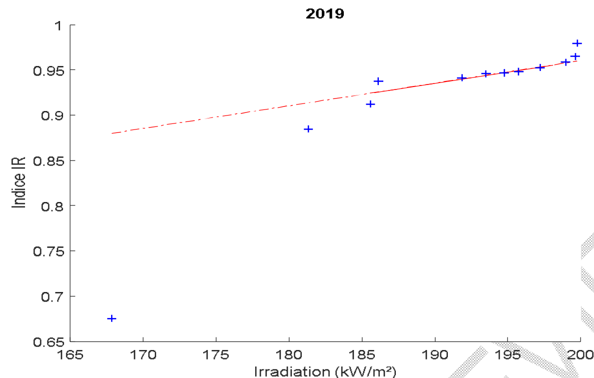

Fig. 3. Correlation between I_R and irradiation for the year 2019, *R^2=0.018*

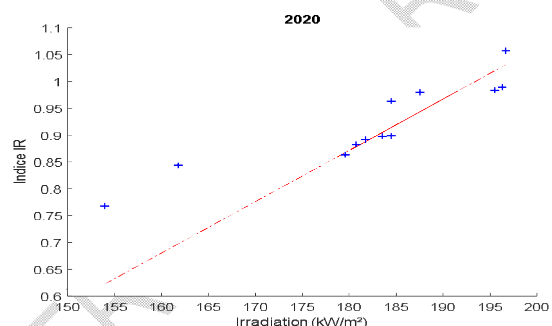

Fig. 4. Corrélation between I_R and irradiation for the year 2020, *R^2=0.023*

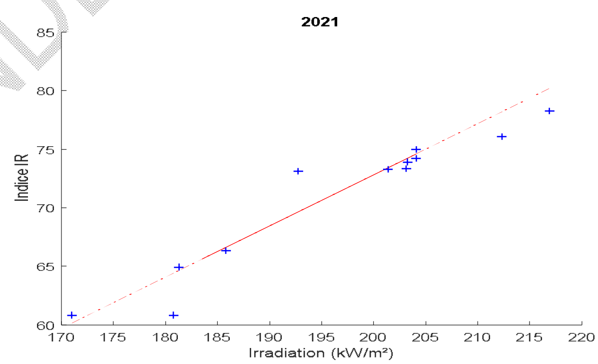

Fig. 5. Correlation between I_R and irradiation for the year 2021, *R^2=0.046*

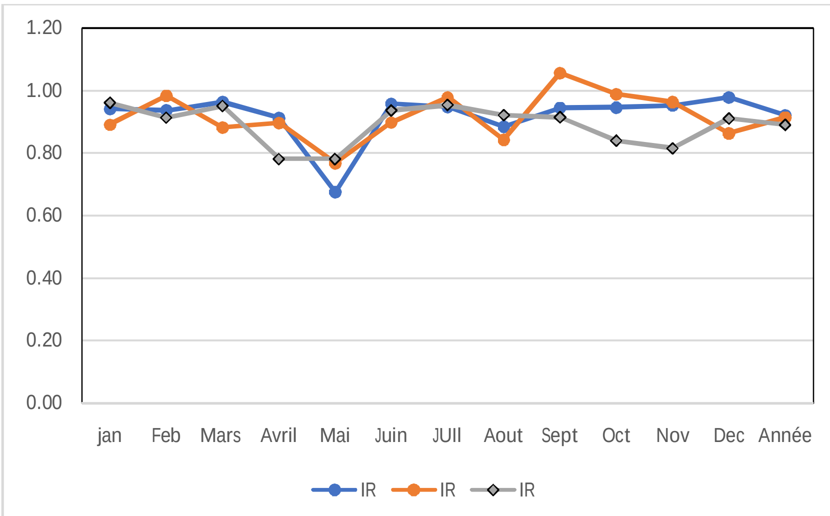

Fig. 6. Annual variation of the I_R index.

The I_R index varies from 0.67 to 1.06. Table 3 presents the annual average of the I_R for each year. The results show that the annual averages of the I_R are close to 1 (perfect case). This means that there is a difference between the theoretical and the actual PR. This difference is due to the unfavorable operating conditions, it does not depend on the weather conditions. Moreover, the I_R index is very close to 1 and it is always higher than 0.91, which implies a good agreement between the actual and the theoretical PR.

Table 3. Average annual I_R index

Year	2019	2020	2021
IR	0,921	0,914	0,891

The I_R index therefore represents the reliability level of the PV system, which is 91% on average per year. Moreover, we can see that this index decreases over the years. This decrease shows that the PV system is degrading over time. The annual degradation rate can be estimated at about 1% per year. The values of I_R are shown in Table 3.

Table 4 summarizes the previously published DR of PV systems studied in the literature and the results of this work.

Comment [A1]: Explain!

Table 4. Comparison of degradation rates per year with some other studies

Locality	Rate of degradation by year (%)	Methodology	Reference
Italie	1.2	Ratio of power	[5] :~~M.~~ Malvoni et al~~l~~., 2017
Djibouti	1.01	PV-USA	[6] :~~D. H.~~ Daher and ~~L.~~ Gaillard., 2018
Inde	0.55 à 0.95	Linear least-squares regression (LSS)	[7] :~~S.~~ Kirmani and ~~M~~ Kalimullah~~.~~, 2017
Thailand	0.5	Simple linear regression model (SLR)	[8] : ~~A.~~ Limmanee *et al, 2015*
Saida, Algeria	0.58	Linear least-squares regression (LSS)	[9] : Silvestre et al., 2018
Alkmaar, Netherlands	0.92	Seasonal and trend decomposition using loess (STL)	[10] : Tabatabaei et al., 2017
Lecce, Italy	0.52	Linear least-squares regression(LSS)	[2] : Malvoni et al., 2017b
Bolzano, Italy	1.48	Classical seasonal decomposition (CSD)	[11] : Lindig et al., 2018
Tsukuba, Japan	2.35	Linear least-squares regression (LSS)	[12] : Ishii et al., 2011
Golden, CO, USA	0.71	Classical seasonal decomposition(CSD)	[13] : Huang et al., 2016
Ankara, Turkey	0.40	Linear least-squares regression (LSS)	[14] : Ozden et al., 2017
Netherlands	0.923	Seasonal and Trend decomposition using Loess (STL)	[15]:Chawla et al., 2021
Malbaza, Niger	**1**	**Report of performance ratio values**	**Our result**

Comment [A2]: To?

~~***Table 4. Comparison of degradation rates per year with some other studies***~~

From the collection of degradation studies shown in Table 4, it can be seen that LSS (5 studies) is the most widely used method in the literature for estimating degradation. It estimates a DR between 0.40% per year[14] and 2.35% per year [12]. The CSD method (2 studies) estimates a DR of 0.71% per year [13]and 1.48% per year[11]. The STL method (2 studies) estimates the same DR of 0.92% per year[10], [15]. The other methods (1 study), SLR, Power Ratio and PV-USA estimate DRs of 0.5% per year, 1.2% per year and 1.01% per year respectively[8], [5], [6].

This result is in line with the reference degradation rates calculated by the authors of other studies (1%/year), as shown in Table 4.

4. CONCLUSION

PV system degradation and reliability studies are strategic tools to evaluate the performance of a PV system [2]. This study contributes to the study of the performance of PV systems in the Sahelian climate. It also allows a comparative study with other climatic zones. The objective is to study the degradation and reliability of the solar PV power plant, located in Malbaza, Tahoua region, Niger, through a comparative analysis of measured and simulated performance ratios. The theoretical model of the PV system was implemented using the PVsyst software. The expected ratio generation index I_R was introduced to perform the evaluation. The results show that the reliability of the PV system depends on the operating conditions. It is not directly due to weather variations. A good agreement between the theoretical and actual energy production allowed to quantify the reliability of the PV system up to 91%. Furthermore, the degradation can be estimated at 1% per year over the three years of operation.

REFERENCES

[1] A. I. Abdoulkarim, B. Seibou, and M. Saidou, "Comparative study with PVsystsoftware of the energy production of the 7 MW," pp. 6157–6161, 2020.

[2] M. Malvoni, A. Leggieri, G. Maggiotto, P. M. Congedo, and M. G. De Giorgi, "Long term performance, losses and efficiency analysis of a 960 kWP photovoltaic system in the Mediterranean climate," *Energy Convers. Manag.*, vol. 145, pp. 169–181, 2017, doi: 10.1016/j.enconman.2017.04.075.

[3] A. I. Abdolukarim, B. Seibou, N. T. Soumaila, and M. Saidou, "Empirical Models for Estimating Global Solar Radiation at the Site of the 7MW Photovoltaic Solar Power Plant in Malbaza (Niger)," vol. 7, no. 7, pp. 45–54, 2020.

[4] A. Issaka Abdoulkarim, B. Seibou, A. Nabil, N. Talibi Soumaila, and M. Saidou, "Analysis of Electrical Disturbances on the Operation of the 7 Mw Photovoltaic Solar Power Plant Connected To the Malbaza Electricity Grid (Niger)," *Int. J. Adv. Res.*, vol. 8, no. 9, pp. 169–180, 2020, doi: 10.21474/ijar01/11647.

[5] M. Malvoni, M. G. De Giorgi, and P. M. Congedo, "Study of degradation of a grid connected photovoltaic system," *Energy Procedia*, vol. 126, no. September, pp. 644–650, 2017, doi: 10.1016/j.egypro.2017.08.263.

[6] D. H. Daher and L. Gaillard, "Évaluation Experimentale De La Degradation Des Performances D ' Une C Entrale Solaire Pv Fonctionnant," no. May, 2018.

[7] S. Kirmani and M. Kalimullah, "Degradation Analysis of a Rooftop Solar Photovoltaic System—A Case Study," *Smart Grid Renew. Energy*, vol. 08, no. 06, pp. 212–219, 2017, doi: 10.4236/sgre.2017.86014.

[8] A. Limmanee *et al.*, "Field performance and degradation rates of different types of photovoltaic modules: A case study in Thailand," *Renew. Energy*, vol. 89, pp. 12–17, 2016, doi: 10.1016/j.renene.2015.11.088.

[9] S. Silvestre, A. Tahri, F. Tahri, S. Benlebna, and A. Chouder, "Evaluation of the performance and degradation of crystalline silicon-based photovoltaic modules in the Saharan environment," *Energy*, vol. 152, pp. 57–63, 2018, doi: 10.1016/j.energy.2018.03.135.

[10] S. A. Tabatabaei, D. Formolo, and J. Treur, "Analysis of performance degradation of domestic monocrystalline photovoltaic systems for a real-world case," *Energy Procedia*, vol. 128, no. January 2018, pp. 121–129, 2017, doi: 10.1016/j.egypro.2017.09.025.

[11] S. Lindig, I. Kaaya, K. A. Weis, D. Moser, and M. Topic, "Review of statistical and analytical degradation models for photovoltaic modules and systems as well as related improvements," *IEEE J. Photovoltaics*, vol. 8, no. 6, pp. 1773–1786, 2018, doi: 10.1109/JPHOTOV.2018.2870532.

[12] T. Ishii, T. Takashima, and K. Otani, "Long-term performance degradation of various kinds of photovoltaic modules under moderate climatic conditions," *Prog. Photovoltaics Res. Appl.*, vol. 19, no. 2, pp. 170–179, 2011, doi: 10.1002/pip.1005.

[13] C. Huang, M. Edesess, A. Bensoussan, and K. L. Tsui, "Performance analysis of a grid-connected upgraded metallurgical grade silicon photovoltaic system," *Energies*,

vol. 9, no. 5, 2016, doi: 10.3390/en9050342.
[14] T. Ozden, B. G. Akinoglu, and R. Turan, “Long term outdoor performances of three different on-grid PV arrays in central Anatolia – An extended analysis,” *Renew. Energy*, vol. 101, pp. 182–195, 2017, doi: 10.1016/j.renene.2016.08.045.
[15] S. Chawla and V. A. Tikkiwal, “Performance evaluation and degradation analysis of different photovoltaic technologies under arid conditions,” *Int. J. Energy Res.*, vol. 45, no. 1, pp. 786–798, 2021, doi: 10.1002/er.5901.