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Performance Ratio and Loss Analysis for a Grid-Connected Solar Photovoltaic System: Case of the 7MW Plant in Malbaza, Niger

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The use of solar energy in sunny countries is an efficient way to overcome the energy shortage. The interest of this energy is not only economic but also environmental, as it emits few greenhouse gases. Niger, a vast landlocked country in the Sahel, is characterized by an average sunshine duration of 8.5 hours per day and an estimated average level of sunshine of around 5 to 7 kW/m2 per day. However, the rate of access to electricity in Niger remains very low. To address this problem, a 7MW solar photovoltaic power plant has been built by the State of Niger in the town of Malbaza. It is composed of monocrystalline photovoltaic panels and injects its energy into the

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national grid. The objective of this study is to compare the performance ratio determined by measurements with that obtained by simulation under PVsyst in order to evaluate its efficiency. The study is based on annual energy production data, recorded at the site, from 1 January 2021 to 31 December 2021. The annual average values of the global irradiation of the site, the energy produced by the system and the energy injected into the grid are respectively 249.86kWh/m², 1225.25MWh and 972.62MWh; those of the ambient temperature and the performance ratio (PR) are respectively 29.78°C and 0.795. The global losses caused by meteorological phenomena and those linked to the technologies of the various components of the system are evaluated at 20.10%.

Keywords: Solar PV system; performance ratio; grid connected system; reference yield.

1. INTRODUCTION

The energy situation in Niger is characterised by limited access of the population to the various forms of modern energy. The rate of access to electricity in Niger for the year 2018 is approximately 13% (National Electricity Access Strategy, 2018). In Niger, the average duration of insolation is 8.5 hours/day and the average power received is between 5 and 7 kW/m²/day [1,2]. To address the problem of access to electricity, a 7MW solar photovoltaic power plant has been built by the State of Niger in the town of Malbaza. The aim of this work is to study the performance ratio of this plant and to compare it with the one obtained from the simulation results. The theoretical model was implemented using PVsyst software. Several studies have shown that this software gives a good estimation of meteorological and electrical data [3-8].

2. MATERIALS AND METHODS

The site of the solar photovoltaic power plant in Malbaza has the following geographical coordinates : longitude 5.52° E, latitude 13.97° N and altitude 325 m. It occupies an area of 45 hectares. Fig. 1 shows the synoptic diagram of the Malbaza solar power plant [9].

The PV array is divided into two blocks : Block 1, which has a peak power of 4 MW and Block 2, a power of 3 MW. The output of both blocks is fed into a 20 kV busbar, after conversion via inverters. Table 1 summarizes the plant components. The characteristics of the solar PV modules and inverters installed in this power plant are given in Tables 2 and 3.

The energy produced by the panels is fed into the electricity grid (Fig. 1). Solar PV panels have a low energy yield. It is therefore necessary to transfer the energy produced to the grid with the least amount of loss. To achieve this, the following parameters must be eliminated : shade, dust, rain, and excess heat.. These environmental factors cause losses in the PV system and further losses occur in system components such as cables, inverters and transformers [10,11].

The International Electrotechnical Commission standard (IEC-61724) specifies the set of measures proposed for the evaluation of PV installations (PR, Yf, Yr...). The performance ratio PR is determined by the equaltion1 [12-15].

$$PR = \frac{Y_f}{Y_r}\ (\%) \quad (1)$$

Where :

Y_f : refers to the final yield of the system and Y_r : refers to the reference yield. These two yields are given by equations (2) and (3) :

$$\boldsymbol{Y_f} = \frac{\boldsymbol{Eac}}{\boldsymbol{Po}}\ (\text{h/d}) \quad (2)$$

$$\boldsymbol{Y_r} = \frac{\boldsymbol{Ipo}}{\boldsymbol{Go}}\ (\text{h/d}) \quad (3)$$

Where :

Po is the peak power of the plant (7MW) and G_0 = 1kW/m²; Ip_0 (kW/m²): plane of array irradiance ; Eac (kW.h) : energy output ; h/d : hour per day.

3. RESULTS AND DISCUSSION

3.1 Interpretation of Results

The simulation result at the design phase of the Malbaza plant, in terms of monthly performance indicators, is summarized in Table 4 [16].

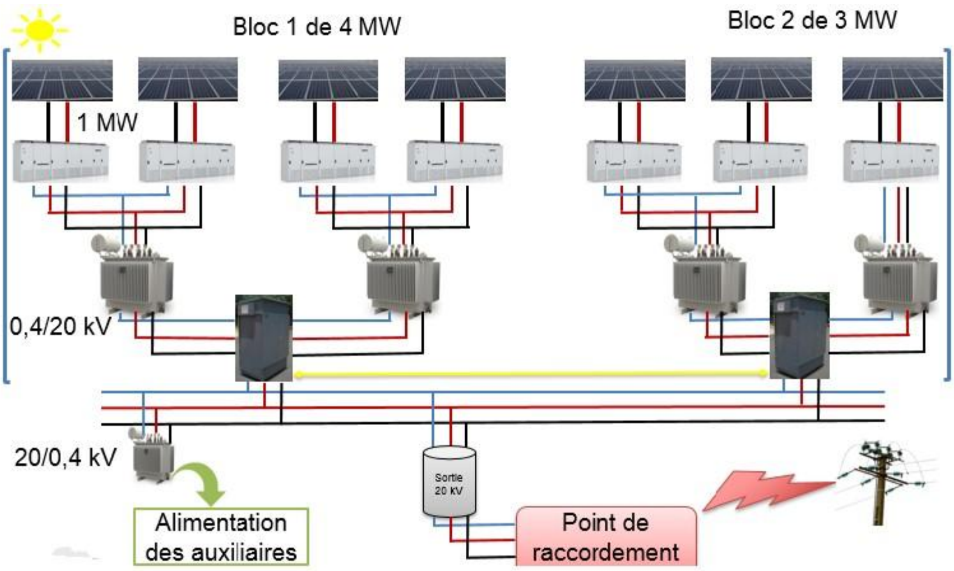

Fig. 1. Architectural plan of the power plant

Table 1. Summary of plant elements

Equipment	Block 1	Block 2	Total
Main transformer	2	2	4
Inverter	4	3	7
Photovoltaic module	12,096	9135	21,231
String Combiner (SCB)	24	19	43
Photovoltaic panel support	288	218	506

Table 2. Characteristics of the PV module

Parameter	Value and unit
Maximum power (Pmax)	330 Wc
Maximum power voltage (Vmp)	36.55 Vdc
Maximum power current (Imp)	9.03 A
Open circuit voltage (Voc)	45.60 V
Short circuit current (Isc)	9.40 A
Maximum system voltage	1000 Vdc
Ground	22.50 kg
Dimensions	1960*990 mm^2
Number of cells per module	96

Table 3. Inverter specifications

Parameter	Value
Max. efficiency	98.80 %
Weight	2 600 kg
Total number installed	7
Input variables	
Max DC power	1 200 kWc
DC MPPT voltage range	600-850 Vdc
Max DC voltage	1 000 V
Max DC current	1 710 A
Output variables	
AC rated power	1 000 kW
AC rated voltage	400 V
AC rated current	1 445 A
Frequency	50Hz

Table 4. Main annual results for one year

	Ir-GlobHor	Ir-Diff-Hor	Tamb	Ir-GlobInc	Ir-GlobEff	E_{pv}	Eac	Y_f	Y_R	PR
January	167,8	52.86	24.06	187.1	177.0	1105	1067	152,43	187,10	0.814
February	176.4	49.58	27.12	190.7	181.2	1110	1071	153,00	190,70	0.802
March	203.1	73.34	31.26	210.7	199.4	1204	1163	166,14	210,70	0.788
April	200.5	80.83	34.45	199.8	188.6	1127	1089	155,57	199,80	0.778
May	196.8	89.29	34.94	190.5	179.2	1075	1038	148,29	190,50	0.778
June	189.6	84.76	32.17	181.0	169.9	1036	1001	143,00	181,00	0.789
July	183.7	87.75	29.87	176.7	165.7	1023	987	141,00	176,70	0.797
August	180.8	96.51	28.45	178.0	166.8	1039	1003	143,29	178,00	0.805
September	184.8	81.15	29.60	188.2	177.3	1090	1053	150,43	188,20	0.799
October	192.9	65.60	31.55	205.4	194.4	1175	1136	162,29	205,40	0.789
November	174.8	45.49	28.32	194.7	184.1	1124	1085	155,00	194,70	0.796
December	164.5	45.97	25.45	186.5	175.8	1089	1051	150,14	186,50	0.805
Year	**2215.8**	**853.14**	**29.78**	**2289.3**	**2159.6**	**13197**	**12746**	**151,71**	**190,78**	**0.795**

Thus, the values of global irradiation, ambient temperature, energy and performance ratio are estimated at 2215.8 kWh/m², 29.78°C, 13,197 MWh and 0.797 respectively.

The simulation results show a slight variation in the value of the performance ratio over the 12 months of the year. It ranges from 77.8% in April-May to 81.4% in January. This result also means that 21% of the insolation is not converted into useful energy and is therefore lost. The energy loss diagram predicting various losses by the PVsyst software is presented in Fig. 2. The annual global horizontal irradiation received by the PV system is estimated to be 2216 kWh/m². Due to shading, soiling loss factor and IAM (Incidence Angle Modifier) factor, the effective irradiation on the collectors is 2160 kWh/m². After converting the PV irradiance by 17.07%, the nominal energy to the grid is 15,181 MWh. Furthermore, after losses due to irradiation level (-0.6%), temperature (-10.4%) and inverter (-1.7%), the resulting energy sent to the grid is 12,745 MWh per year. Table 5 summarizes the expected system losses.

The analysis of actual production data for the year 2021 indicates a variation in the performance ratio, depending on the month:

- 60.82%, in the months of April-May: minimum ;
- 78.27%, in January: maximum, (Fig. 3).

3.2 Comparaison between Simulated and Measured PR

The performance ratio (PR) is one of the most important parameters to evaluate the photovoltaic installation efficiency. It refers to the ratio between the actual energy yield and the Most possible energy yield [17,18]. Fig. 4 shows the comparaison between the simulated and measured PR. From the observation of this figure, it can be seen that the performance ratio becomes lower in the experimental result than in the simulated, notably, during the hottest months in Niger (60.83%), April and May. In January, the highest PR values are observed: experimentation (78.27%) and simulation (81.4%). Apart from April-May and November-October, there is good agreement between the measured and simulated PR.

We have correlated the PR obtained from the measurements with those obtained from the simulation. The representation is given in Fig. 5. The value of the R^2 coefficient found is about 58% which indicates a good correlation between the experimental and simulated values. It should be noted that the most scattered points of simulated PR of the system are due to high losses in the converters, the unavailability of the power plant and the presence of moving clouds that cause a sudden drop in radiation.

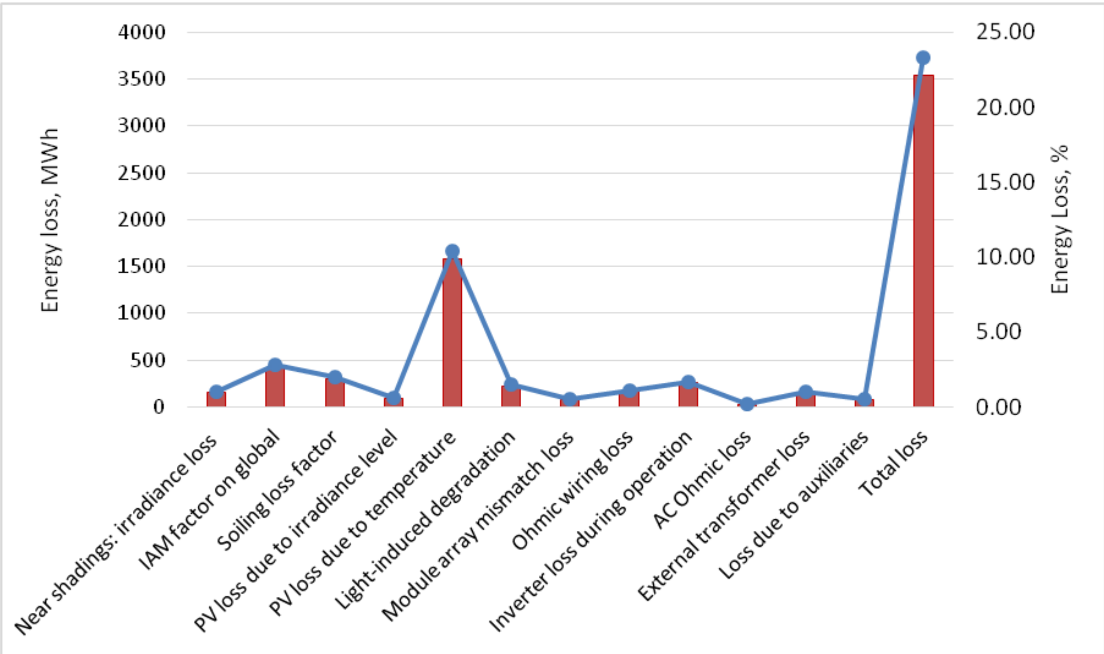

Fig. 2. System loss diagram

Table 5. Predicted system losses

	Losses	Value
1	Irradiation level losses	-2.50%
2	Temperature losses	-10.40%
3	PV Conversion Losses	-3.80%
4	Conversion losses in the inverter (DC to AC)	-1.70%
5	Losses in transformers and auxiliaries	-1.70%
6	**Total**	-20.10%

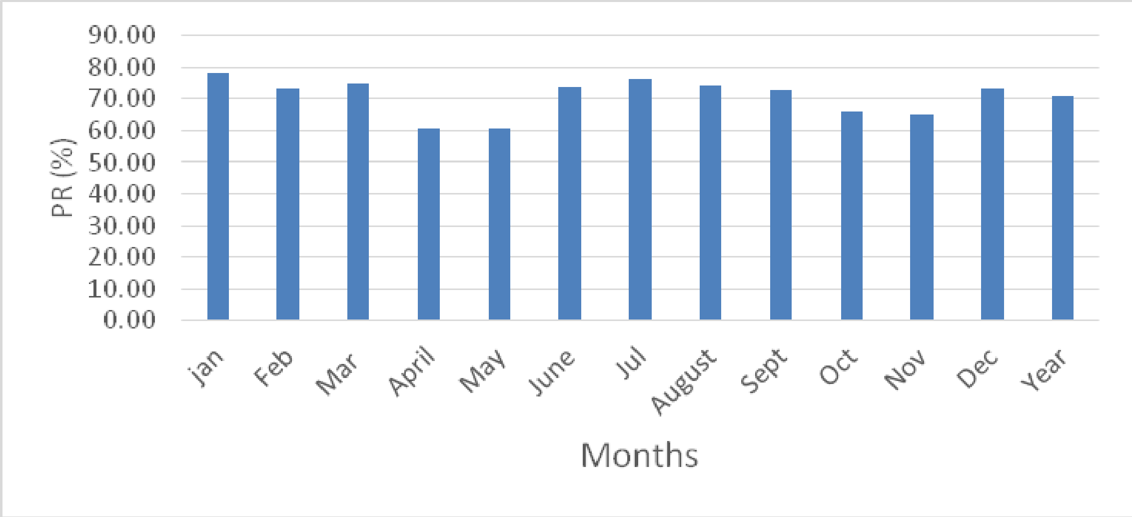

Fig. 3. PR values determined by the measurements

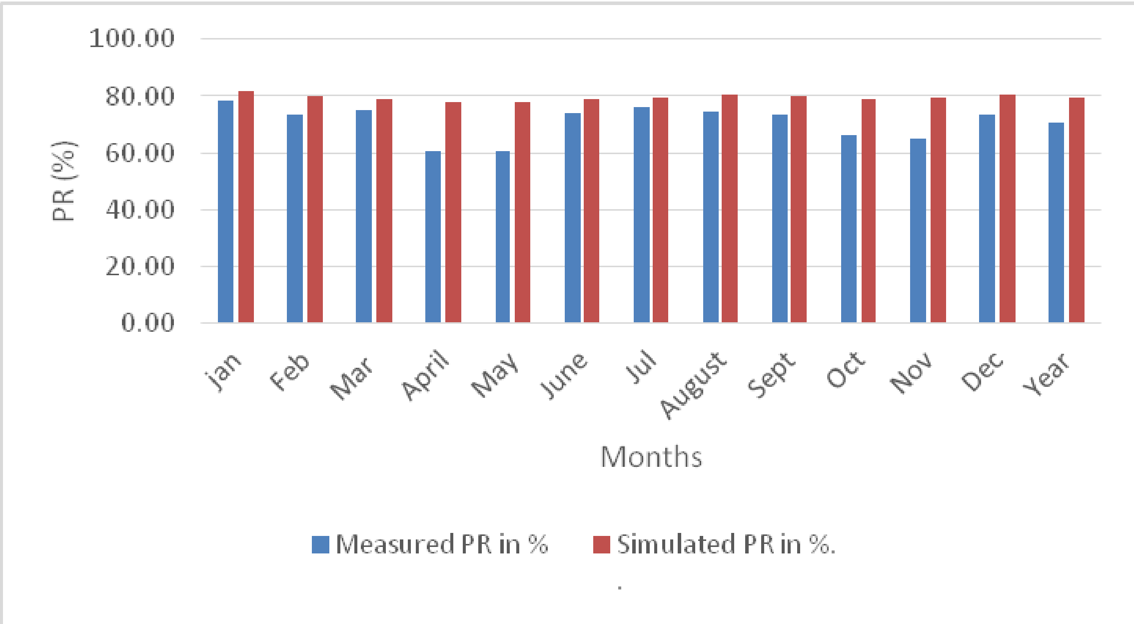

Fig. 4. Comparison between measured PR and simulated PR

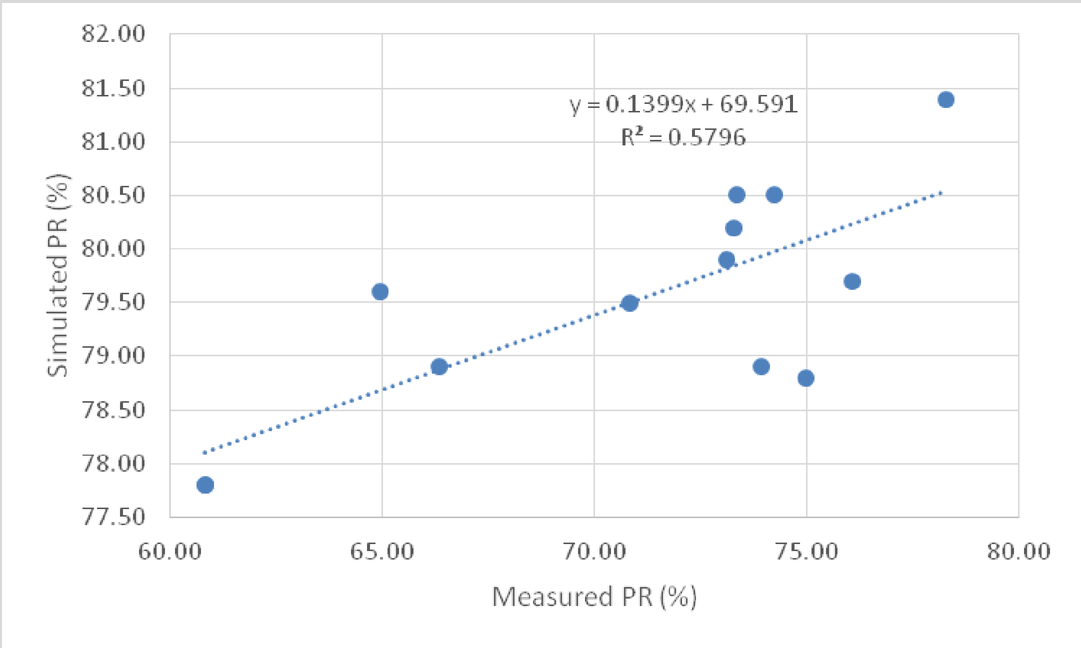

Fig. 5. Correlation between measured PR and simulated PR

4. CONCLUSION

The data recorded along the year 2021 allowed to compare the performance ratio of the 7 MW solar PV system connected to the national grid in Niger. On average, the measured and simulated performance ratio values are respectively 70.84% and 79.5%. These two values show us that the performance of the solar PV system presented in our case study is quite acceptable, but it is still lower than its simulated value. This decrease can be justified by the fact that the grid is not 100% available, the temperature variation, the presence of clouds that block and the conversion losses.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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