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RESEARCH ARTICLE

COMPARATIVE STUDY WITH PVSYST SOFTWARE OF THE ENERGY PRODUCTION OF THE 7 MW PHOTOVOLTAIC SOLAR POWER PLANT CONNECTED TO THE MALBAZA ELECTRICITY GRID (NIGER).

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ABSTRACT

Background : To increase the country's energy production, the State of Niger has built a 7MW photovoltaic solar power plant connected on grid of the Nigerien electricity company in the department of Malbaza, Tahoua region (13^0 58'3.54 "North and 5^{0}31'11.95 " East). **Objective:** In order to analyze the operation of this plant, a study of energy production was carried out in this article. **Methods**: The study was based on data on energy production as a function of irradiation and temperature from January 1, 2019 to December 31, 2019. A comparative study was first carried out between the monthly energy production of the plant and those established by the designer with the Pvsyst software on a provisional basis. The comparative study was then made between the monthly energy productions of the power plant and those obtained by simulation on the Pvsyst software using the irradiations and the actual temperatures of the site and the same inclination of the modules. **Results**: The first study showed that the statistical values of the Mean Bias Error (MBE), of the Mean Absolute Bias Error (MABE) and of the Root Mean Square Error (RMSE) of the monthly energy productions are respectively 62.1MWh, 69.150MWh and 91.722MWh with a mean percentage error (MPE) of 6.575% and a correlation coefficient of 36.28%. But the low correlation coefficient of 21.49% for the irradiation did not allow any conclusion to be drawn on the correct functioning of the system. For the second study, the values of MBE, MABE and RMSE obtained are respectively 60.096MWh, 92.975MWh, 123.591MWh with an MPE of 5.811% and a correlation coefficient of 70%. **Conclusion**: These results show an acceptable operation of the plant.

INTRODUCTION

In a rapidly changing global energy context marked by a reduction in conventional fossil fuel resources and constantly growing greenhouse gas emissions, the use of renewable energies remains among the essential solutions to limit the effects of the activity human rights on global warming. Of all the renewable energies, solar photovoltaic (PV) is of particular interest to Africa, since it has a significant solar source. Today, solar photovoltaic power plants are developing at a rapid pace and have reached a technical maturity that allows them to become an important segment of the energy industry. Niger, a vast landlocked country in the Sahel, has an important solar resource. Sunshine is indeed characterized by an average duration of 8.5 hours / day and an average estimated level in the range 5 - 7 kW / m^2 / day. Thus, to improve the country's energy production, the Nigerien authorities have thought about developing photovoltaic solar power plants. It is in this context that the project to build a 7MW photovoltaic solar power plant connected to the electricity grid in Malbaza comes into operation, which was commissioned in November 2018.

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However, the production of a solar power plant depends on meteorological parameters, namely irradiation and temperature [1) (2) (3) (4) (5) (6) (7). The analysis of the energy production of this plant therefore requires a reproduction of its behavior for all irradiation and temperature conditions with estimation or pre-sizing software. This article consists in analyzing the energy production of the said plant using the PV syst software and the energy production data for 2019. We will first present the materials and methods used for this study before presenting the results and their results interpretations.

MATERIALS AND METHODS

Location of the Malbaza photovoltaic solar power plant site : Located at a latitude of 13^0 58'3.54 "North and a longitude 5^{0}31'11.95" East, the photovoltaic solar power plant is located in the department of Malbaza (Tahoua region), about 455 km from Niamey, capital of Niger. The elevation of the site is 325 meters and there is no significant difference in the level of the ground across the area. It is a 7MW photovoltaic solar power plant connected to the public electricity grid. The studied site covers an area of 11 ha and is located at a distance of 1.4 km from the connection station.

Figure 1. Location of the Malbaza power plant.

The installation area of the power plant is as defined in figure 1 below.

•Presentation of the Malbaza solar power plant : The control unit is made up of 21,231 identical modules which have the following characteristics:

Maximum nominal power (Nominal Maximum Power): 330Wc;

Open Circuit Voltage: 45.6V;
Short Circuit Current: 9.65A;

Voltage at nominal power (Voltage at Maximum Power): 36V; Current at Maximum Power: 9.17A. These modules are grouped together in series of 21 modules to form a "string" (row). These strings are distributed in junction boxes called "String Conbiner Box (SCB)". 1MW unit capacity central inverters (see figure above) are used to convert direct current from SCBs to alternating currents. Each inverter has a mini step-down chopper converter with a controller to extract the Maximum Power and to adapt the output voltage of the strings to the input of the inverter. The inverters supply an alternating voltage of 400V AC. The inverters are installed in conditioned centenarians. Transformers are used to increase the voltage from 400V AC to 20,000V AC. A total of four (4) transformers including three of 2.2 MVA and one of 1.1 are used. The 2.2 MVA transformers each have two 400V inputs and one 20000V output and are each powered by two inverters and the 1.1MVA one has a single input and a single output and is powered by a single inverter. These four transformers are then coupled in parallel two by two by Ring Main Unit (RMU). The output of these RMUs is then coupled in parallel on a 20kV busbar to inject energy into the network through a 20kV line of 2km long provided for this purpose. As the 400V busbars are not accessible, a 20kV / 0.4 250kVA auxiliary transformer is used to supply the auxiliary loads.

Measuring equipment: Notwithstanding the current and voltage transformers for current and voltage measurements, the site has a measuring station made up of:

two pyrometers: one for measuring the global radiation on the inclined plane of the modules and the other for measuring the global radiation on the horizontal plane;

two thermometers for measuring the ambient temperature and the temperature of the modules;

The photo of the measurement site are shown in figures 2.

- a hygrometer for measuring humidity;
- a Heliometer for measuring wind speed;
- a pluviometer for measuring rain fall.

These measuring and control devices allow all the parameters of the plant to be monitored from the control room. All of these parameters (electrical and metrological) are recorded by SCADA (Supervisory Control and Data Acquisition) and are accessible from the control room server. The method consists first of all in comparing the monthly values of energy production, irradiation and temperature recorded during one year of operation (from January 1, 2019 to December 31, 2019) with those predicted by the designer with the software. PVsyst, outside of the project. Secondly, we use the monthly irradiation and site temperature values to estimate the power plant energy outputs with the PVsyst software (version V6.43), and compare them with the actual plant output. The comparison between the different parameters is carried out by evaluating the following statistical values: The Mean Bias Error (MBE):

it gives information on the tendency of the model to overestimate the observed values (MBE> 0) or to underestimate them (MBE <0). It is calculated by the following formula [8) [9) [10) [11) [12):

$$MBE=\frac{\sum_{i=1}^{n}(Y_{ip}-Y_{im})}{n} \qquad (1)$$

With

Y_{ip} :Values estimated with PVsyst software (energy production, irradiation or temperature).

Y_{im} : Values measured on site (energy production, irradiation or temperature).

n: the number of series of tripled values (energy production, irradiation and temperature); the Mean Absolute Bias Error (MABE): it corresponds to the average of the absolute relative errors. The closer this value is to zero, the lower the average error the model has. It is calculated by the following formula [8)[9) [10)[11)[12):

Table 1: Comparative values of the power plant's energy production for the year 2019 :

month	Results of measurements on the site in 2019			Designer's Pvsyst simulation results (forecast) [13]			Results of the simulation on Pvsyst with the irradiation and the site temperature of 2019		
	Irradiation on site (kWh/m^2)	Average ambient temperature (°C)	production (MWh)	Irradiation on site (kWh/m^2)	Ambient temperature (°C)	production (MWh)	Irradiation on site (kWh/m^2)	Average ambient temperature (°C)	Production (MWh)
January	196.29	26.93	1101.7	187.1	24.06	1067	196.29	26.93	1256.69
February	187.54	28.3	1064.4	190.7	27.12	1071	187.54	28.3	1159.61
March	179.58	45.42	993.6	210.7	31.26	1163	179.58	45.42	1069.422
April	184.47	37.72	998	199.8	34.45	1089	184.47	37.72	1057.735
may	161.77	46.67	888.1	190.5	34.94	1038	161.77	46.67	899.993
June	181.74	33.1	1007.7	181	32.12	1001	181.74	33.1	992.706
July	180.75	30.82	987.9	176.7	29.87	987	180.75	30.82	991.368
August	153.94	28.7	861.7	178	28.45	1003	153.94	28.7	870.841
September	184.46	31.28	1011.1	188.2	29.6	1053	184.46	31.28	1078.015
October	183.50	31.79	1015.20	205.4	31.55	1136	183.50	31.79	832.923
November	196.69	33.44	1081	194.7	28.32	1085	196.69	33.44	1249.468
December	195.52	37.87	989	186.5	25.45	1051	195.52	37.87	1261.182
Annual values	2186.245	34.34	11998.8	2289.3	29.78	12746	2186.245	34.34	12719.953

The statistical comparison values between the various site parameters (irradiation, temperature and production) and those of the simulation on PVsyt given by designer are summarized in Table 2 below:

Table 2. Statistical values for Comparison between on-site data and forecasts

paramètres	MBE	MABE	MPE	RMSE	R^2	r
Irradiation (kWh/m^2)	8.588	12.752	5.144 %	16.578	0.0462	0.2149
Température (°C)	-4.571	4.571	-11.746 %	6.731	0.3589	0.599
Production (MWh)	62.10	69.150	6.575 %	91.722	0.1317	0.363

The statistical parameters for the comparison between the power plant's energy production and that obtained by simulation on the PVsyst software, taking into account the irradiation and the temperature of the site are summarized in Table 3 below:

Table 3 Statistical values for Comparison between central production and PVsyst software with identical temperature and irradiation

paramètres	MBE	MABE	MPE	RMSE	R^2	r
Production (MWh)	60.096	92.975	5.811 %	123.591	0.490	0.700

$$\text{MABE} = \frac{\sum_{i=1}^{n}\left|(Y_{ip} - y_{im})\right|}{n} \quad (2)$$

•Root Mean Square Error (RMSE): it represents the average error committed in absolute value between the measured values and those estimated by the model, the lower this error is, the more the values simulated by the model are close to the measured values. It is calculated by the following formula [8] [9] [10] [11] [12]:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(Y_{ip} - Y_{im}\right)^2}{n}} \quad (3)$$

- the Mean Percentage Error (MPE): it reflects the average of the error made between the measured values and those estimated by the model. It is calculated by the following formula [8] [9] [10] [11] [12]:

$$\text{MPE}(\%) = \frac{\sum_{i=1}^{n}\left(\frac{Y_{ip} - Y_{im}}{Y_{im}} x100\right)}{n} \quad (4)$$

The coefficient of determination or multiple correlation coefficient R^2: it is the strength of the linear relation between the predicted load values and those actually observed. It represents the proportion of the total variance of the quantity to be estimated that can be taken into account by the estimation variables. The closer the coefficient is to one (1), the stronger the correlation between predicted and observed values. The R^2 is calculated using the following equation [11] [12]: (5)

$$R^2 = \frac{\frac{1}{n}\sum_{i=1}^{n}(Y_{ip} - \overline{Y}_{ip})\cdot(Y_{im} - \overline{Y}_{im})}{\sqrt{\left[\sum_{i=1}^{n}(Y_{ip} - \overline{Y}_{ic})^2\right]\left[\sum_{i=1}^{n}(Y_{im} - \overline{Y}_{im})^2\right]}} \quad (5)$$

With

$\overline{Y}_{ip}$:The annual average of the estimated values; $\overline{Y}_{im}$ The annual average measured on the site.

- The correlation coefficient r: it measures the preponderance of the affine relation between the quantity measured and the quantity to be estimated [11]. It is given by the number r such that:

$$r^2 = R^2 \quad (6)$$

RESULTS

The results of on-site measurements, of the simulation on PVsyst made by the designer on a provisional basis and those of the simulation that we carried out taking into account the irradiation and the temperature and the inclination of the modules (10 ° and azimute 0°) are summarized in Table 1 below:

The statistical comparison values between the various site parameters (irradiation, temperature and production) and those of the simulation on PVsyt given by designer are summarized in Table 2 below:

The statistical parameters for the comparison between the power plant's energy production and that obtained by simulation on the PVsyst software, taking into account the irradiation and the temperature of the site are summarized in Table 3 below:

DISCUSSION

We observe that:

- The statistical values of MBE, MABE, MPE, and RMSE of irradiation are respectively 8.5879kWh/ m^2, 12.752 kWh / m^2, 5.1436% and 16.5782 kWh / m^2, which shows the forecast irradiations are greater than those recorded on the site but in more or less acceptable proportions. However, the correlation coefficient of 0.2149 shows a weak correlation between the two. This could be due to other human activities developed in the central area.
- the statistical values of MBE, MABE, MPE and RMSE of irradiation are respectively -4.5707 ° C, 4.5707 ° C, -11.7455%, 6.7313 0 ° C. This shows that the forecast temperatures are lower than those recorded on the site but in proportions more acceptable than the irradiation with a good correlation of 59.91%.
- The statistical values of MBE, MABE and RMSE of energy production are respectively 62.1MWh, 69.15MWh and 91.7217MWh. This shows that the forecast energy productions are higher than those recorded on the site with a weak correlation of 36.28%, and in proportions less acceptable than temperature and irradiation. But, the MPE value of 6.575% is very acceptable. However, the weak correlation of irradiation does not allow to conclude on the results of energy production. It is therefore necessary to perform a simulation taking into account the irradiation and the temperature of the site.
- The results show a good correlation between the site's monthly energy productions and those obtained by simulation under the same irradiation and temperature conditions, with a good MPE value which is 5.811% and a correlation coefficient of 70%. Which shows a good performance of the solar power plant. However the high values of MBE; MABE and RMSE show that the system faces other disturbances which can be related to the impact of dust, grid disturbances etc.

Conclusion

The study carried out on the energy production of the 7MW solar power plant in Malbaza made it possible, on the one hand, to compare the energy production of this plant with those forecast established during the design of the project, and on the other hand to compare this production with the simulation results of energy production on the PVsyst software. The results obtained showed that the plant was in good working order.

Conflict of interest: The authors declare no conflict of interest in relation to this article.

Contribution of authors

- **Assarid Issaka Abdoulkarim,** Boureima Seibou : documentary research,simulink, writing
- Madougou Saidou : critical reading.

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