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Research Article

INFLUENCE OF METEOROLOGICAL PARAMETERS ON THE PRODUCTION OF GRID-CONNECTED SOLAR PHOTOVOLTAIC PLANTS IN A TROPICAL AREA: CASE OF DIASS (SENEGAL)

[1,] * **Issa RohouLaye Sonko,** [1]**Mame Faty Mbaye,** [2]**El hadji Mbaye Ndiaye,** [1]**Mouhamadou Thiam,** [1]**Mamadou Wade**

[1]Laboratory of Sciences and Techniques of Water and Environment (LaSTEE), Polytechnic School of Thiès, BP A10 Thiès, Senegal.
[2] Research team energetic system and efficiency, Alioune Diop University of Bambey, BP 30, Senegal.

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ABSTRACT

This paper presents a study of the influence of meteorological parameters on photovoltaic (PV) energy production. The study of the impact of four meteorological parameters that are ambient temperature, PV module temperature, wind speed, and solar irradiation is presented. The results obtained showed that solar irradiation is the meteorological parameter that has the greatest influence on PV production: the higher the irradiation, the higher the energy production. For average ambient temperatures between 20 and 30 °C, the influence of temperature on production is insignificant. The temperature of the PV modules decreases from 29.6 °C to 28.64 °C between March 01 and April 01 while the production also decreases from 168.15 kWh to 138.95 kWh depending on the irradiation during the same period.

Keywords: Weather parameters, connected grid, solar PV plant, irradiation, and ambient temperature.

INTRODUCTION

Over the past decade, grid-connected solar PV power plants have grown significantly [Ndiaye *et al.,* 2020]. A number of studies have been conducted on the performance evaluation of grid-connected plants installed around the world. These studies examine the performance of grid-connected PV systems under different climatic conditions. The performance of PV plants is related to in-situ weather conditions such as irradiance, ambient temperature, PV module temperature, and wind speed [Bassam *et al.,* 2017]. For example, a study of the impact of PV module temperature and wind speed on production showed that PV production decreases with PV module temperature and that high wind speeds minimize module thermal inertia [Akhsassi *et al.,* 2016]. Authors have also shown that wind speed has a significant impact on the temperature of a PV module and thus on the production of that module. The wind speed lowers the module temperature and thus improves the production [I. V Leleux]. In this work, the influences of meteorological parameters on the Diass power plant in Senegal are studied. The objective is to show the impact of each meteorological parameter on the photovoltaic production. Real data from the Diass power plant are programmed in the Matlab Simulink software for simulation and correlation with other results. This is done to show the reliability of the Diass plant data. Then, these real daily average data of each month of the Diass power plant (irradiation, ambient temperature, PV module temperature, wind speed, and energy production) are simulated to evaluate the impact of each meteorological parameter on the PV production.

MATERIALS AND METHODS

The field of experimentation is the solar PV plant of Diass. This plant is connected to the national electrical grid of Senegal. It has a total installed power of 23 MWp. Geographically, the site of the plant is located in the town of Diass. It is part of the district of Sindia, in the department of Mbour, in the region of Thiès (Senegal). It is located between longitudes 14°10' and 14°50 West and latitudes 14°32 and 15°45 North. Table 1 presents the characteristics of the PV modules of the plant. The power plant consists of 85,608 PV modules.

Tableau 1: Characteristics of PV modules

Parameters	Values
Short circuit current (A)	**9.23**
Current at maximum power point (A)	**8.69**
Open circuit voltage (V)	**38.1**
Voltage at maximum power point (V)	**31.1**
Maximum power (W)	**270**

The experimental data are collected over one year. They are the daily average data of each month. The measurements are made for 5 min steps. The data consist of solar irradiation (W/m²), ambient temperature (°C), PV module temperature (°C), wind speed (m/s) and energy production (kWh). Table 2 gives the coordinates of the site of the Diass solar PV plant.

Tableau 2 : Geographical coordinates of the site

Position	Latitude	Longitude
North-West	273391.21	1621250.61
North-East	273654.94	1611107.62
South-East	273345.13	1620536.20
South-West	273081.40	1620679.19

RESULTS AND DISCUSSIONS

Simulation with real data of Diass solar power plant

Using the Matlab Simulink software, we performed a simulation using the actual daily average data of each month of the Diass power plant as input data, with the aim of proving the reliability of these data. Figure 1 shows the equivalent diagram of a photovoltaic cell under illumination. It corresponds to a current generator Iph connected in parallel with a diode. Two parasitic resistors are introduced in this

***Corresponding Author: Issa RohouLaye Sonko,**
1Laboratory of Sciences and Techniques of Water and Environment (LaSTEE), Polytechnic School of Thiès, BP A10 Thiès, Senegal.

diagram. These resistors have some influence on the characteristics I =f (V) and P =f(V) of the cell

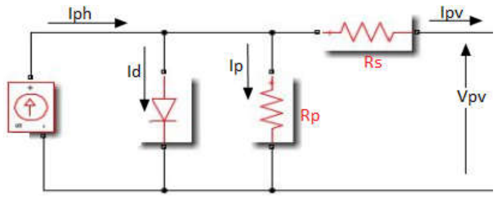


Figure 1 : Equivalent electrical diagram of a solar cell

The diagram shown in Figure 1 is modelled by equation (1).

$$I_{pv} = \left[I_{sc,stc} + K_i\left(T_{pv}(t) - 25\right)\right]\frac{I_r(t)}{1000} - I_s\left[e^{\left(\frac{V_{pv}+I_{pv}.R_s}{nV_T}\right)} - 1\right] - \frac{V_{pv}+I_{pv}.R_s}{R_p} \quad (1)$$

V_T is the thermal voltage of the cell.
n is the ideality factor of the diode.
I_(sc,stc) is the short circuit current under the STC.

Figure 2 shows the influence of illumination on the characteristics I=f(V) and P=f(V). At a constant temperature, the current changes significantly, but the voltage changes slightly because the short-circuit current is a linear function of the irradiance, whereas the open-circuit voltage is a logarithmic function.

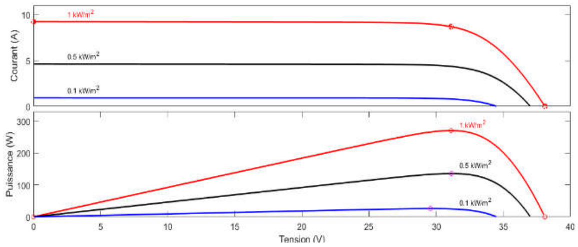


Figure 2: Influence of irradiation on the IV and PV characteristics

Figure 3 shows the influence of temperature on the I=f(V) and P=f(V) characteristics. It is essential to understand the effect of changing the temperature of a solar cell on the I=f(V) characteristic. The current depends on the temperature since the current increases slightly as the temperature increases, but the temperature negatively affects the open circuit voltage. When the temperature increases, the open circuit voltage decreases. Therefore, the maximum power of the generator is reduced.

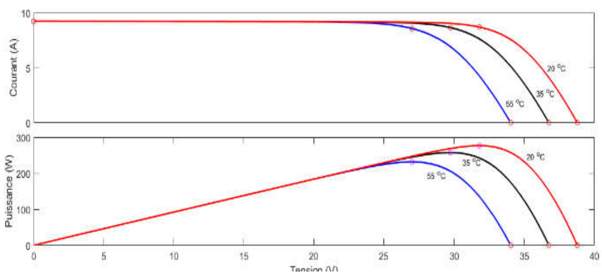


Figure 3: Influence of temperature on the I-V and P-V characteristics

On the other hand, the influence of module temperature (Tpv) and irradiation is more noticeable on the short circuit current (Isc) and on the open circuit voltage (Voc) as modelled by equations (2) and (3) respectively.

$$I_{sc}(t) = \left[I_{sc,stc} + K_i\left(T_{pv}(t) - 25\right)\right]\frac{I_r(t)}{1000} \quad (2)$$

$$V_{oc}(t) = V_{oc,stc} - K_v(T_{pv}(t) - 25) \quad (3)$$

With K_i: temperature coefficient of the current [/ °C]; K_v: temperature coefficient of the voltage [/ °C].

For N modules, the short-circuit current and open-circuit voltage are related to the maximum power (Pmax) by the form factor (FF) according to equation (4).

$$P_{max}(t) = N \times V_{oc}(t) \times I_{sc}(t) \times FF \quad (4)$$

These results are similar to those obtained by some authors [1],[2],[3],[4] in the literature. With these reliable plant data, we will evaluate in the next part the impact of each meteorological parameter on the PV production.

Impact of weather parameters on PV production

After simulating the daily average data of each month of the plant, we obtain the following figures. Figures 4 to 6 show, respectively, the variation of short circuit current and open circuit voltage with temperature and the variation of short circuit current with irradiation. The energy production of a PV module is intimately related to three main electrical parameters: maximum power, short-circuit current, and open-circuit voltage. We notice in Figure 4 that the short-circuit current increases with the module temperature. This is due to a narrowing of the band gap of the PV cell and results in an increase in the recombination rate of the electron-hole pairs.

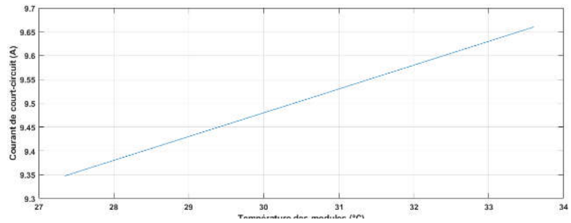


Figure 4: Variation of the short-circuit current as a function of temperature

On the other hand, in Figure 5, we notice that the open circuit voltage decreases with the temperature of the module. This is a consequence of the thermal agitation caused by the increase in temperature.

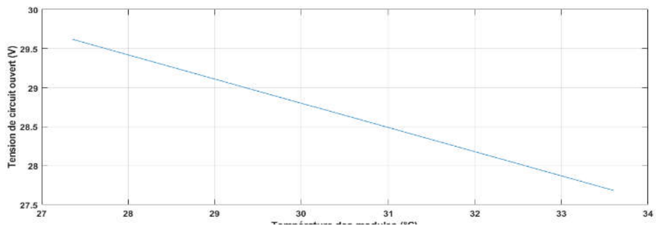


Figure 5: Variation of the open-circuit voltage temperature

Figure 6 shows that the short-circuit current increases with irradiation. Indeed, both the short circuit current and the open circuit voltage are functions of temperature. The mathematical models given in the equations show that the short circuit current increases with temperature contrary to the open circuit voltage. This increase would be due to the phenomenon of pair electron hole recombination in the PN junction of the PV cell.

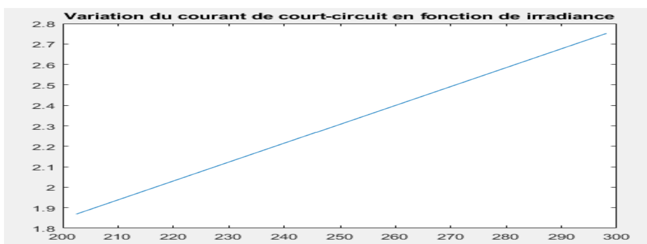


Figure 6: Variation of the short circuit current with irradiation

Figures 7 to 10 show the evolution of electrical quantities with respect to meteorological parameters. Figure 7 shows the variation of the ambient temperature and the temperature of the modules. These variations do not seem to have a direct impact on the fluctuations of the energy production. The temperature variations are in an ideal range for the operation of the solar panels. The various production decreases observed are likely due to the influence of other meteorological parameters such as irradiation.

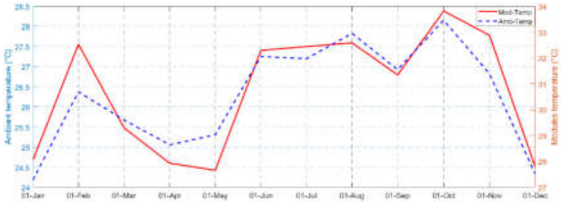


Figure 7: Variation of ambient temperature and module temperature

The variation of the wind speed is given in Figure 8. We observe average wind speeds between 1.2 and 2.99 m/s at 10 m height in the Diass site. These wind speeds adequately ventilate the PV modules. This decreases the temperature and has the effect of increasing the yield and therefore improves the production.

Figure 8: Variation in wind speed

Figure 9 shows the variation in solar irradiance. It can be seen that the irradiation is higher during March and decreases during July in the Diass site. Production peaks during the months of high irradiation. This has a strong influence on production. The higher the irradiation, the higher the production.

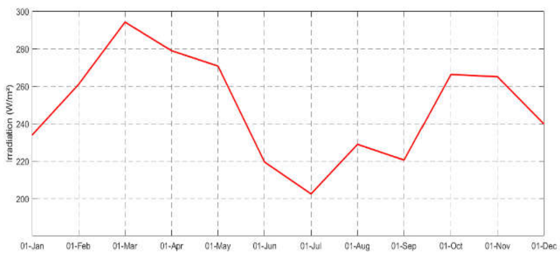


Figure 9: Variation in solar irradiation

The production of the power plant is given by Figure 10 and that it is during March that the production is higher in the Diass site.

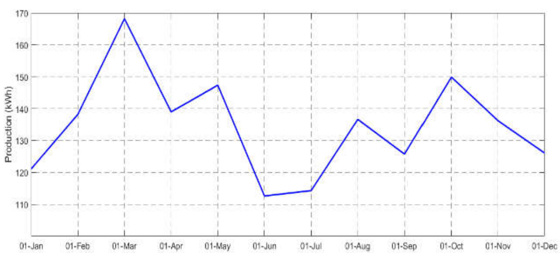
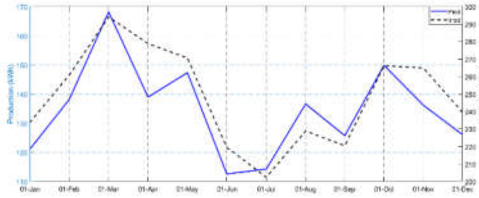
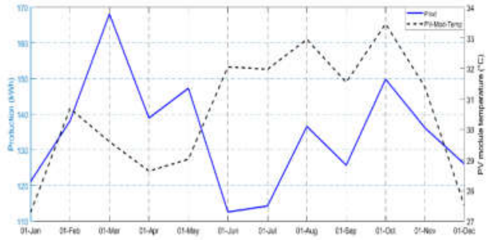


Figure 10: Variation of PV production

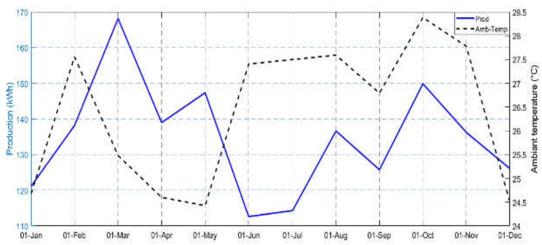
Figures 11a, 11b, 11c, and 11d show the influence of weather parameters on PV production. We see that irradiation is the parameter that has the most impact on PV production. The analysis of Figure 11.a) shows a strong correlation between PV production and irradiation. Days of peak irradiation correspond to the days of peak energy production. Days of decreasing irradiation coincide with drops in energy production. This shows that production is strongly dependent on irradiation.



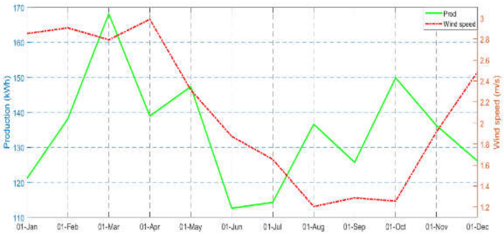
11.a) Evolution of the production according to the solar irradiation. However, for certain values of the temperature of the PV modules, we notice that the evolution of the production follows that of the temperature. The production increases when the temperature of the PV modules decreases. This is the case between June 01 and July 01 (Figure 11.b) where we notice a decrease in the temperature of the PV modules (32.06 to 31.74 °C) which leads to an increase in production (112.59 to 114.28 kWh) despite a significant decrease in irradiation (222.51 to 203.46 W/m²). This can be explained by the fact that temperature is also a essential parameter of the PV module. Low temperature values (below 25 °C) increase the PV production.



11.b) Evolution of the production as a function of the temperature of the PV modules Figure 11.c) shows the evolution of the production as a function of the ambient temperature. The ambient temperature does not seem to have any influence on the PV production between 24.42 and 28.8 °C. This can be explained by the fact that for average ambient temperatures below 30 °C, the thermal agitation in the cells is not very significant. This does not vary the recombination rate of the electron-hole pairs too much.



11.c) Evolution of the production as a function of the ambient temperature, Figure 11.d) shows the evolution of the production as a function of the wind speed. We notice that the wind speed does not seem to have any influence on the PV production between 1.20 and 2.99 m/s for a height of 10 m.



11.d) Evolution of production as a function of wind speed. The extreme values of the data used are presented in Table 3.

Tableau 3: Extreme values of meteorological parameters

Parameter	Minimal value	Maximal value
Ambiant temperature (°C)	24.42	28.38
PV modules temperature (°C)	27.28	32.95
Wind speed (m/s)	1.20	2.99
Irradiation (W/m²)	202.44	294.09
Production (kWh)	112.59	168.15

From the analysis of Figures 11 a, 11b, 11c, and 11d, it can be seen that the temperature of the PV modules and the irradiation have a great impact on the photovoltaic energy production and thus the output of the plant. The higher the irradiation, the higher the production. The temperature of the modules (below 25° C) increases the production. On the other hand, ambient temperature and wind speed do not seem to have any influence on PV production in their respective observed ranges (between 24.42 and 28.38 °C and between 1.20 and 2.99 m/s).

CONCLUSION

We have performed a simulation using as input the real daily average data of each month of the Diass power plant through the Matlab Simulink software. This is done to show the reliability of the real data of the Diass power plant. Then, these real data of the Diass power plant are simulated to evaluate the impact of each meteorological parameter on the PV production. The obtained results showed that the irradiation and the temperature of the PV modules have a strong influence on the photovoltaic energy production of the plant. On the other hand, ambient temperature and wind speed do not seem to have any influence on PV energy production in their respective observed ranges (between 24.42 and 28.38 °C and between 1.20 and 2.99 m/s). Meteorological variability affects the solar power generation system. The actual meteorological data of the power plant is used to estimate the renewable energy resources, to ensure the balance between supply and demand, to plan maintenance operations, etc.

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