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IMPACT of CLIMATIC PARAMETERS on the PERFORMANCE of the DIASS PHOTOVOLTAIC POWER PLANT in SENEGAL

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***Abstract*— Senegal, characterized by a semi-arid climate, has a high level of solar irradiation, which is highly favorable to photovoltaic production to meet the country's growing energy demand. However, the climatic conditions at the sites where grid-connected photovoltaic power plants are installed are an obstacle to their efficiency. The aim of this study is to assess the impact of climatic parameters such as temperature and dust at the Diass power plant over one year, using the IEC 61724-1 standard. The results of the study reveal an average annual irradiation of 5.83 kWh/m², a correction of the temperature performance ratio ranging from 3.15% to 6.13% and a daily degradation of 0.28% of the power plant's performance caused by the effect of dust on the modules. To maintain a performance degradation of less than 5%, the Diass power plant needs to be cleaned every two weeks.**

Keywords— Photovoltaic power plant, IEC 61724-1 standard, Semi-arid, Climatic parameters, Senegal

I. INTRODUCTION

The development of renewable energies is a current political requirement. In the short term, a deficit of energy from known resources is not foreseeable, but long-term scenarios already exist, which demand a global reduction in the production of polluting substances, in particular C02. These problems have led to a frantic race towards new forms of energy. The development of renewable energies in Senegal is part of the strategy to secure the country's energy supply and reduce its dependence on imported fossil fuels[1]. However, the development of photovoltaic solar power is coming up with a number of difficulties, including the presence of dust deposits on the surface of the panels and the high temperatures of the solar modules. The performance of photovoltaic solar power plants at different sites around the world generally varies according to the module technology, the plant configuration and the climatic conditions in the area[2]. Several recent studies, such as those in [3], [4], [5], [6] show that climatic conditions, such as dust accumulation and high temperatures, have a major influence on the performance of solar power plants. The work of [7] shows that solar energy losses caused by soiling on a global scale could be estimated at 7 billion euros in 2023. According to [3], the accumulation of dust on modules results in a significant reduction in their performance, particularly in dry and semi-arid climates. Although semi-arid zones have a high solar potential favorable to photovoltaic production, these zones are often confronted with high temperatures and significant dust deposits on the surface of the modules, as in the case of the Sahel [8]. The study of [9] in Saudi Arabia shows soiling losses of 2% to 18% over a 30-day period for different technologies. Similarly, [10] reveals a 28% degradation in power output after 60 days without cleaning. Another study [11] in a semi-arid area of Brazil shows a reduction in power output of 18.72% after 70 days. The work of [7] in Morocco shows a soiling rate of 7.48% after 30 days, with a daily rate of 0.25% during the dry season. The study by [12] in Santiago, Chile, reveals a daily degradation in module performance due to dust that varies between 0.13% and 0.56%. Finally, the study by Aidara et al. [13] carried out in Dakar, Senegal, shows a 14.89% degradation in module production after two months without cleaning.

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Although dust causes significant losses if no cleaning action is applied, the effect of temperature in hot climates on module output is even greater, as demonstrated by the work of [6], which reveals a 0.7% reduction in performance ratio for every 1°C increase in ambient temperature. Another study carried out in Iran shows an average correction of the temperature performance ratio under standard test conditions of 4.22% for polycrystalline technology [14]. The work of [15] shows a correction of the performance ratio in temperature which varies from 4% to 7% for polycrystalline modules in Kuwait. Finally, Gopi et al. [16] estimate a performance ratio correction of 6.18% during the summer and 4.87% in December during the winter in a 10 MWp solar photovoltaic plant in Colorado. And the study of Al-Maghalseh [17] in Palestine shows an improvement in module performance as wind speed increases.
In Senegal, the effect of dust and temperature on solar panels has been the subject of several studies. However, these studies do not take into account large-scale power plants connected to the SENELEC distribution network. The Diass photovoltaic solar power plant (23 MWp), which is one of the largest solar power plants in the country, was the subject of this study in order to determine the influence of the site's climatic parameters on performance. The aim of this new study is to assess the effect of both temperature and dust on the performance of the Diass power plant. It will thus contribute to improving the efficiency of our power plants and to a better approximation of the performance ratio for the installation of other solar photovoltaic power plants in the country.

II. MATERIALS AND METHODS

The Diass solar power plant is located in the commune of Diass, about 40 km south-east of Dakar in the department of Mbour, in the Thiès region. It has an installed capacity of 23,114 MWp over an area of 40 ha (14°39N, 17°06W) and was commissioned in 2019 (Figure 1).

A. *PRESENTATION of the DIASS POWER PLANT*

The solar power plant consists of 85,608 polycrystalline modules (Q. POWER-G5), 32 inverters (ConextTM Core XC) and 16 transformers (1360Kva). The modules have a power output of 270Wp each and are mounted at a 15° angle facing south. The characteristics of these modules are given in Table 1. In this study, real electrical and meteorological data (DC and AC energy, solar irradiation, ambient and module temperature, wind speed, humidity, rainfall) for the entire year 2022 acquired at 5-minute increments from the plant's SCADA platform are used to assess the impact of climatic parameters on performance.

Fig. 1 Diass photovoltaic solar power plant

TABLE I TECHNICAL CHARACTERISTICS of STC MODULES

Type Modules	Q. POWER-G5

Maximum power (Pmax)	270Wp
Maximum voltage (Vmax)	31.1V
Maximum current (Imax)	8.69A
Voltage Open circuit (Voc)	38.1V
Current Short circuit (Isc)	9.23A
Module efficiency (η_{PV})	16.5%
Temperature coefficient (Pmax)	-0.4%/°C
Temperature coefficient (Voc)	-0.31%/°C
Temperature coefficient (Isc)	0.05%/°C

B. METHODOLOGY

The performance parameters defined in standard IEC 61724-1 and described below are used to assess the influence of climatic parameters on the performance of the power plant:

1) Reference and Final yields :

This is the ratio between the irradiation received on the surface of the modules H_t and the reference irradiation H_{STC} under standard test conditions(STC) [2].

$$\boldsymbol{Y_r = \frac{H_t}{H_{STC}}} \quad (\boldsymbol{kWh/kW}) \qquad (1)$$

Y_r represents the number of hours of maximum sunshine in a day.
The final yield of the PV system Y_f represents the ratio between the AC energy produced at the output of the inverters E_{AC} and the nominal power of the installation P_{nom} [18].

$$\boldsymbol{Y_f = \frac{E_{AC}}{P_{nom}}} \quad (\boldsymbol{kWh/kW}) \qquad (2)$$

2) Performance ratio :

The performance ratio (PR) is the most widely used measure for evaluating the performance of photovoltaic installations. The PR measures the efficiency of the whole installation as a converter of solar irradiation into AC energy and can be seen as a measure of efficiency, standardized to take account of both the size of the array and the solar resources available [19].
This is the ratio between the final yield of system Y_f and the reference yield Y_r.

$$\boldsymbol{PR = \frac{Y_f}{Y_r}} \quad (\%) \qquad \textbf{(3)}$$

The PR captures the combined effect of all losses that occur in the installation, including modules, inverters, transformers, electrical wiring and system or grid downtime.

3) Temperature-corrected performance ratio :

In order to assess the impact of temperature on plant performance, the performance ratio was corrected for temperature. The temperature-corrected PR (PRC_{STC}) eliminates the effects of temperature and gives a better idea of how a photovoltaic plant operates [19].

$$\boldsymbol{PRC_{STC} = \frac{PR}{1+\gamma\times(T_{mod}-T_{mod,ref})}}\textbf{(\%)} \qquad \textbf{(4)}$$

With : γ: temperature coefficient in Pmax
T_{mod}: Module temperature
$T_{mod,ref}$: (25°C)

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The effect of temperature on panel production is determined using the temperature-corrected performance ratio. In fact, once the performance ratio is corrected for temperature, any variation in it can be attributed to the effect of dust [15]. As a result, during periods without the power plant being cleaned, performance deteriorates due to the accumulation of dust. The daily performance degradation rate will therefore be obtained by linear regression over the uncleaned period of the modules.

III. RESULTS AND DISCUSSION

In this section, the effect of the site's climatic parameters such as irradiation, wind, temperature, dust and rain on the plant's performance is analyzed and discussed.

A. Effect of irradiation and wind on power plant production

Irradiance at the Diass site varies according to the month, increasing to reach maximum values in February, March and April before decreasing to reach minimum values in July, August and September. Figure 2 reveals that the site's irradiation is generally high throughout the year, which is highly favorable for photovoltaic production. Irradiation varies from a maximum of 6.53 kWh/m² in March to a minimum of 4.93 kWh/m² in August, generally marked by the rainy season, as shown in Figure 2. This figure also shows that module production is proportional to site irradiation, with maximum production in April and minimum production in August.

Figure 3 shows the monthly variations of wind speed, with peaks in February, March and April. These favorable winds during this period cause the modules to cool down, which improves their efficiency and therefore production. This reflects the indirect effect that wind speed can have on the production of solar power plants.

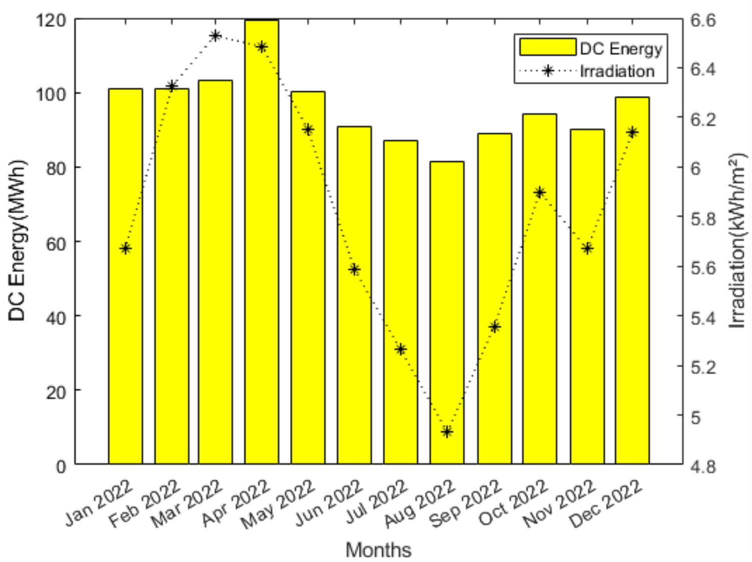

Fig. 2 Monthly variation of daily average energy with irradiation

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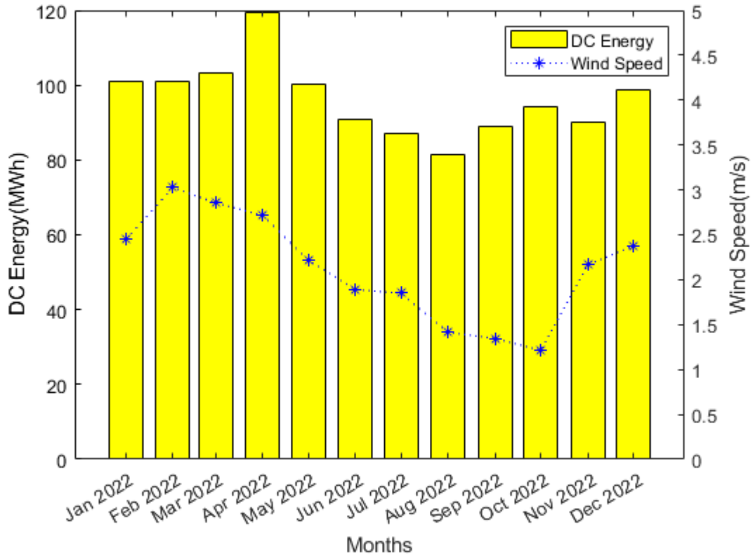

Fig. 3 Monthly variation of daily average energy with wind

B. Temperature effect

Figure 4 shows that the temperature of modules at Diass power plant is highly dependent on the ambient temperature at the site. Indeed, the periods recording high module temperatures correspond to the period where the ambient temperature is very high and exceeds an average of 30°C. The ambient temperature at the site varies from a minimum of 25.67°C in March to a maximum of 31.09°C in November. Thus, maximum module production is observed during periods of low ambient temperature, as shown in Figure 5. This high production is explained by the fact that module efficiency is better when the temperature of the modules is low. Figure 6 represents the PR and PRC_{STC} performance ratios, and reveals a variable correction ranging from 3.15% in March to 6.13% in October. This correction is more significant the higher the site temperature. We can also see from Figure 6 that the PRC_{STC} is more stable than the PR throughout the year because any variation caused by the increase of temperature during the seasons is eliminated.

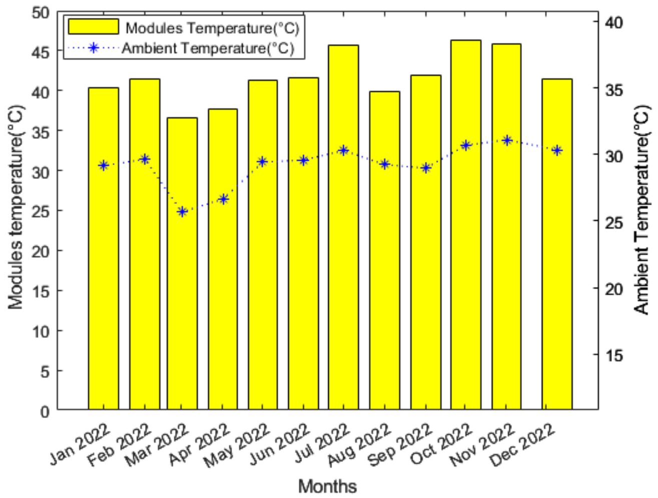

Fig. 4 Monthly variation of ambient temperature and modules

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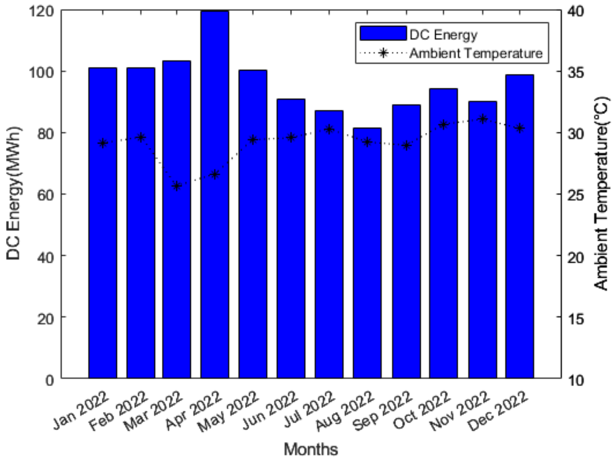

Fig. 5 Monthly variation of daily average energy with temperature

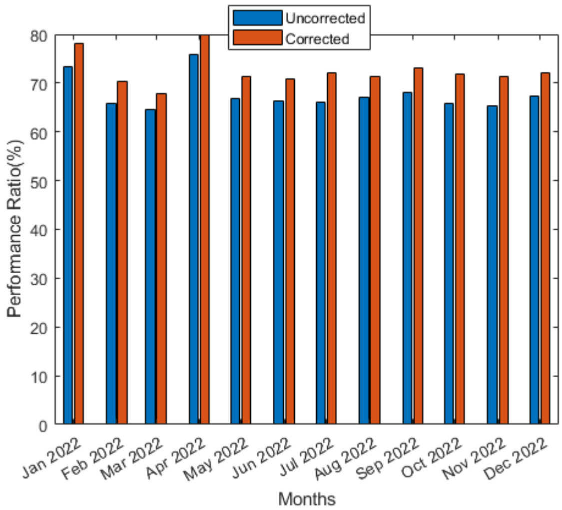

Fig. 6 Temperature-corrected and uncorrected performance ratio

C. Soiling effect

Short-term module production depends on several factors such as irradiation, temperature, dust and wind. In order to quantify the effect of dust only on plant performance, the PR, which is standardized to take account of variations in irradiation, is used on the one hand, and the PRCstc on the other, which eliminates the effect of temperature. Any variation in the PRCstc is therefore caused by the effect of dust on the modules. Figure 7 shows the degradation in performance due to dust over two periods without cleaning the power plant during the dry season. During the first period, from January to March, the plant was left without cleaning due to a malfunction in the cleaning system, which led to a significant degradation of performance. So, the longer the plant remains without cleaning, the more its performance deteriorates. Table 2 summarizes the rate of performance degradation obtained by linear regression during periods when the modules were not cleaned, with an average of 0.28%/day. The results of this table also show that the quantity of dust deposits varies according to the month, and is greater during the January-March period. These results are in perfect agreement with the study by [20], which shows that dust events in the Sahel are greatest between December and April and are strongest in February and March. Therefore, based on this daily performance degradation rate, cleaning every fortnight becomes necessary in order to maintain degradation below 5% during the dry season.
The meteorological records for Diass show that on 20 July 2022 there was an episode of rain that improved the plant's performance. Figure 8 shows the beneficial effect of the rain, which corrected performance by almost 7%.

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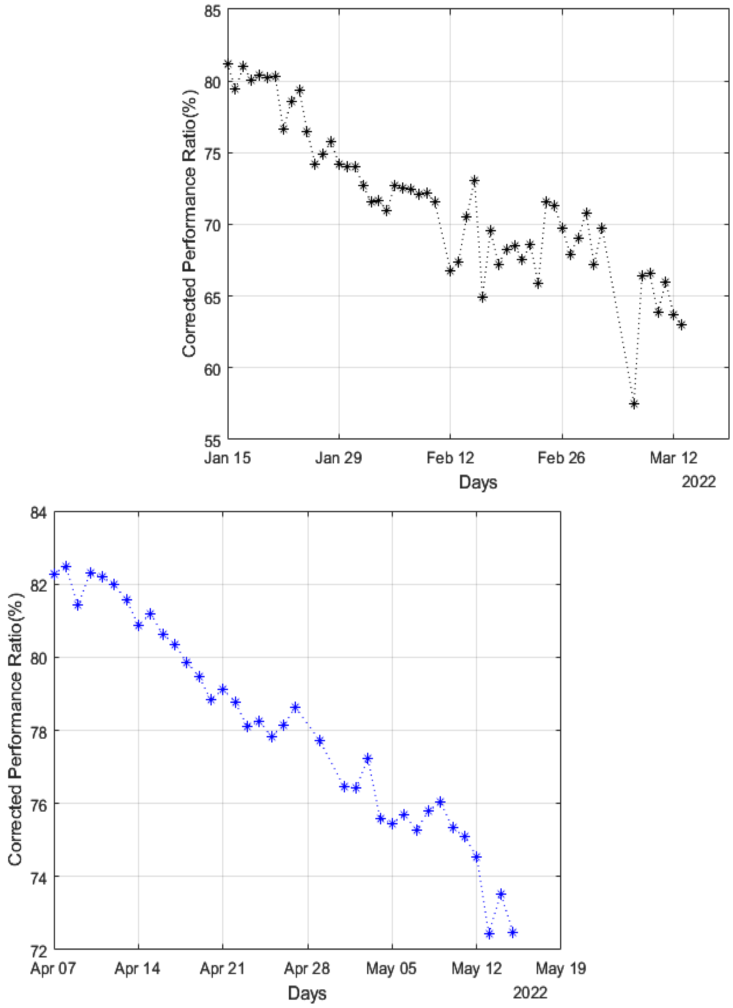

Fig. 7 Performance degradation due to dust

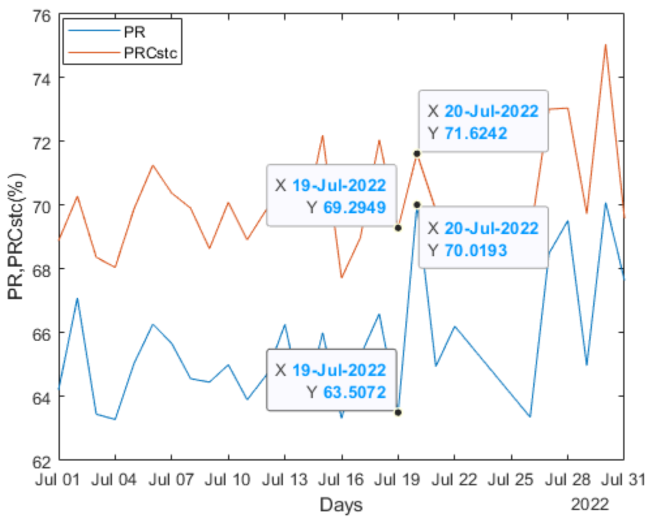

Fig. 8 Correction of performance due to the rain effect

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TABLE II PERFORMANCE DEGRADATION DURING UNCLEANED PERIODS

Periods	Number days	Degradation rate (%)	%/day
January-March	58	18.19	0.31
April-May	39	9.79	0.25

IV. Conclusions

The influence of climatic parameters on the performance of the Diass power plant was studied and revealed the extent to which severe site conditions can affect the plant's performance. The plant's performance is severely affected by the high temperatures at the site throughout most of the year, with a correction in the temperature performance ratio that varies from 3.15% to 6.13% compared with the normal performance ratio. There is also a degradation in performance at an average daily rate of 0.28% caused by dust on the surface of the modules and favourable winds which favour module production by causing the modules to cool. As a result, cleaning every two weeks will keep performance degradation below 5%.

A better understanding of the influence of the site's climatic parameters will enable us, in a forthcoming study, to set up an accurate prediction model for the energy produced by the plant.

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