Vol. 16(4), pp. 115-122, October-December, 2021
DOI: 10.5897/IJPS2021.4953
Article Number: 920AFE367888
ISSN 1992-1950

http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

Performance analysis of the 23 MWp grid connected photovoltaic plant in Diass Senegal

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Received 20 May, 2021; Accepted 14 September, 2021

This paper presents the performance analysis of a 23 MWp photovoltaic solar power plant installed in Diass, Senegal. The solar photovoltaic power plant is composed of 85608 polycrystalline PV modules and 8 transformer stations (TS). Each TS consists of 4 inverters, several DC BOX and 2 transformers. The environmental and performance data of the plant used in this work were recorded throughout the year 2020. The performance parameters evaluated in this work are array yield, reference yield, final yield, array capture losses, system losses, performance ratio and capacity factor. The results of this study have been compared to other work carried out around the world. The results show that the performance depends on the climatic conditions of the on-site installation and the technologies used.

Key words: Performance analysis, power plant, performance data, environment data, PV plant, grid connected.

INTRODUCTION

Clean or renewable energy refers to all forms of energy production from inexhaustible sources available on a human timescale. Renewable energies have a low impact on the environment which contribute to fight the greenhouse effect and global warming.

Global consumption and electricity production by renewable energy reached 19.3 and 24.5%, respectively between 2015 and 2016 (Global Overview, 2017). In 2019 more than 200GW of electrical power has been installed in the world. Most of them come from the solar photovoltaic installations which has a great success around the world (REN21, 2020).

Among the different types of renewable energies, photovoltaic (PV) solar energy is the most widely applied energy in human life and industrial field (Lu et al., 2020). In terms of exploitation, solar panels need to be installed to the outdoor conditions which contribute to the degradation of the PV modules performances. The performance of a grid connected PV system depends more on cell technologies, installation configuration and

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operating conditions (maintenance) than on meteorological parameters (Attari et al., 2016). The performance evaluation needs to monitor the production and operation of the PV power plant during its runtime (Elhadj Sidi et al., 2016). Over the years, many studies analyzed the performance of photovoltaic installations around the world.

Attari et al. (2016) evaluated the performance of a 5 kWp grid-connected PV system installed on the roof of the building in Tangier in Morocco. They obtained the final yield ranging from 1.96 to 6.42 kWh/kWp, a performance ratio (PR) ranging from 58 to 98% and an annual capacity factor of 14.48% (Attari et al., 2016).

In Brazil, the performance of a 2.2 kWp PV system installed at the State University of Ceara Fortaleza was monitored from June 2013 to May 2014. The annual energy yield, plant yield, final yield, annual average daily plant yield, system losses, system and inverter yields, PR and capacity factor were calculated. The results that they found show the good potential of producing electricity through photovoltaic solar energy in the state of Ceará – Brazil (de Lima et al., 2017). Nouar (2020) calculated the final yield, reference yield, system efficiency, performance ratio and total losses of a 20 MWp grid-connected PV system installed in a harsh environment in southern Algeria for a period of one year. The results obtained show that the installation of photovoltaic stations gives good results encouraging investments in this region (Nouar, 2020). Mpholo et al. (2015) monitored the performance of a first newly installed PV solar farm at the Moshoeshoe I International Airport in Lesotho with a capacity of 281 kWp, the result of this study shows that the area is suitable for grid-connected PV systems. The analysis period covers both hot summer and cold winter (Mpholo et al., 2015). In Italy, Congedo et al. (2013) analyzed the performance of a 960 kWp PV system composed of silicon monocrystalline PV modules over an eight-month period. The final energy yield, system efficiency, performance ratio and temperature losses of the PV cells were calculated. The analysis of the performance in this study is according to results reported in literature for PV system located in the Mediterranean (Congedo et al., 2013).

In Senegal, many PV solar power plants are installed and others are at the project stage. Table 1 lists the PV solar power plants installed in Senegal.

The main objective of this paper is to analyze the performance of a 23 MWp solar PV system in polycrystalline grid-connected technologies. The study covers the period from January to December 2020.

Description of Diass PV power plant

The Diass photovoltaic solar power plant is located at 40 km southeast of Dakar, Senegal, on latitude 14.38°N and longitude 17.05°W, and 40 m above sea level.

Table 1. PV Solar power plants installed in Senegal.

Name	P(MW)	Date
CICAD	2	2015
Bokhol	20	2016
Malicounda	20	2016
Santhiou Mékhé	30	2017
Mékhé Mérina	30	2017
ERS Kahone	20	2018
Sakal (Louga)	20	2018
Diass (Thies)	23	2019
Kael	35	2020
Scaling Kahone	43,9	2020

The Diass PV power plant consists of 85608 polycrystalline modules (model: Q. POWER-G5 270) inclined at an angle of 15°, 32 inverters (ConextTM Core XC), 16 transformers. The system is installed on an area of 400000 m^2 and divided into two sections: Diass one with 15 MWp and Diass two with 8 MWp. The detailed information of Diass plant is shown in Table 2. The first section of the Diass power plant has 55584 modules, five transformers stations (TS), each TS is composed of four inverters and two transformers. The second unit of the power plant consists of 30024 modules, three TS, twelve inverters and six transformers. The simplified block diagram of the PV system is given by Figure 1. The PV plant is equipped with a monitoring system which continuously and instantaneously measures the inverter data, system status and weather data. The information collected is stored and sent to an IP network. All data is stored in intervals of 5 min. The characteristics of the PV modules, transformers and invertesr are shown in Tables 3, 4 and 5, respectively.

METHODOLOGY

To analyze the impact of the environmental parameters on the PV system production and evaluate the seasonal and monthly performance, one year of data was recorded from January to December, 2020, then the calculation was made using Matlab.

The performance parameters evaluated in this study are array yield, reference yield, final yield, array capture losses, system losses, performance ratio and capacity factor. The results of this study were compared to other studies carried out worldwide.

All the performance parameters are calculated according to IEC 61724 standards. The various performance parameters shown in Table 6 were applied to the recorded data.

RESULTS AND DISCUSSION

The results of the various performance parameters are shown in Table 7. The results are shown in the following section.

Table 2. Diass installation.

N°TS	P(VA)	$P_{STC}(W_C)$	String	Module	DC BOX	Pkva/Ppv
1	2720000	2993760	462	11088	26	0.909
2	2720000	2993760	462	11088	26	0.909
3	2720000	2993760	462	11088	26	0.909
4	2720000	3013200	465	11160	26	0.903
5	2720000	3013200	465	11160	26	0.903
6	2720000	2779920	429	10296	24	0.978
7	2720000	2663280	411	9864	23	1.021
8	2720000	2663280	411	9864	23	1.021
Total Diass	21760000	23114160	3567	85608	200	0.94

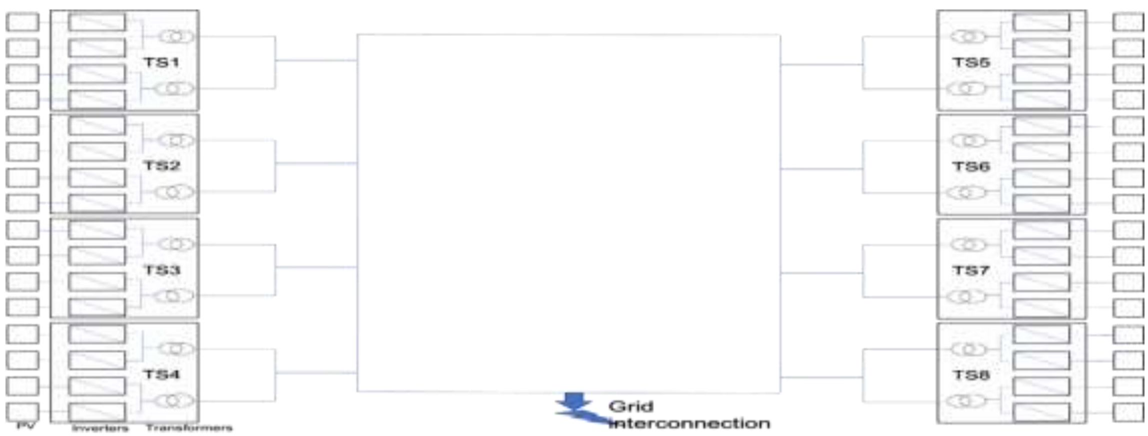

Figure 1. Simplified diagram of Diass solar PV plan.

Table 3. Technical characteristics of PV system in STC.

Module type	Si-poly
Pm (W)	270
Isc (A)	9.23
Voc (V)	38.1
Imax (A)	8.96
Vmax (V)	31.3

Table 4. Technical characteristics of transformer.

Transformer 1360 KVA 3 Phased 50 Hz		
Impedance (%)		6.47
Maxi Ambient (°C)		45
P0 (W)		1912.0
PK (W)		15770.0
	HV	**LV**
Rated Voltage (V)	33415	380
Currents (A)	23.5	1033.2

Table 5. Technical characteristic of inverter.

Model No.	XC 680
Input Data DC	
Max DC voltage	1000 V
Max DC current	1280 A
Voltage range MPPT	550-800 V
Output Data (AC)	
Max AC power	680 KW
Nominal AC voltage	380 V
Nominal AC current	1040 A
Frequency	50-60 Hz
Distortion (THD)	<3%
Max. efficiency	98.9%
Euro Efficiency	98.7%

The monthly average wind speed is as shown in Figure 2. The monthly average wind speed varies from a minimum of 1.203 m/s in August to a maximum of 2.986 m/s in April. The wind speed has a very significant impact

Table 6. The various performance parameters.

Parameter	Description	Mathematical expression	Unit
Array yield (Y_a)	Array yield is the total of energy output from the PV array during the monitoring period divided by the nominal power of the installed array (Attari et al., 2016).	$Y_a = \frac{E_{PV}}{P_{nom}}$	kWh/kWp/day
Reference yield (Y_r)	Reference yield is the ratio of the global solar radiation and the array reference irradiance in the STC (Attari et al., 2016).	$Y_r = \frac{H}{H_R}$; H_R = 1 Kwh/m^2	kWh/kWp/day
Fianal yield (Y_f)	Final yield or system yield, is the ratio of the annual, monthly or daily AC energy generated by the PV divided by the power of the installation (Elhadj Sidi et al., 2016).	$Y_f = \frac{E_{AC}}{P_{nom}}$	kWh/kWp/day
performance ratio (PR)	The performance ratio (PR) indicates the overall effect of system losses (PV, cables, inverters, weather conditions), on a PV array's normal power output. The performance ratio gived by the ratio of array yield Y_a and reference yield Y_r (Attari et al., 2016).	$PR = \frac{Y_a}{Y_r} \times 100$	%
Capacity factor (CF)	The capacity factor (CF) is the ratio of the actual energy output of the PV system and the PV system energy generates operating at full rated power (Nouar, 2020).	$CF = \frac{E_{AC}}{P_{nom}} \times 100$	%
Array capture losses (L_C)	They represent all the losses that occur during operation of the PV modules (Elhadj Sidi et al., 2016).	$L_C = Y_r - Y_a$	kWh/kWp/day
System losses (L_{cm})	The system losses caused by the inverter losses (Attari et al., 2016).	$L_S = Y_a - Y_f$	kWh/kWp/day

Table 7. Results of the performance parameter over the monitoring period.

Parameter	Yr (kWh/kWp/day)	Ya (kWh/kWp/day)	Yf (kWh/kWp/day)	Lc (kWh/kWp/day)	Ls (kWh/kWp/day)	PR	CF(%)
January	5.00	4.01	3.94	0.993	0.068	0.788	16
February	5.55	4.40	4.33	1.150	0.070	0.780	16
March	5.89	4. 63	4.55	1.262	0.076	0.773	19
April	5.64	4.44	4.36	1.200	0.075	0.774	18
May	5.26	4.14	4.07	1.120	0.068	0.774	17
June	4.85	3.84	3.77	1.008	0.065	0.779	15
July	4.37	3.48	3.42	0.890	0.063	0.782	14
August	4.49	3.59	3.52	0.901	0.065	0.785	15
September	4.97	3.96	3.89	1.005	0.071	0.783	16
October	5.37	4.26	4.19	1.111	0.072	0.780	17
November	5.22	4.16	4.08	1.061	0.073	0.783	16
December	4.96	3.97	3.90	0.987	0.070	0.787	16
Year	5.13	4.07	4.00	1.057	0.070	0.780	16

on the natural cleaning and cooling of the solar panels.

The monthly variation of the average daily module temperature and the average daily ambient temperature for the month is as shown in Figure 3. The temperature varies from a high of 28.41°C in October to a low of24.38°C in January, while the panel temperature varies from a high of 33.83°C in October to a low of 27.24°C in January.

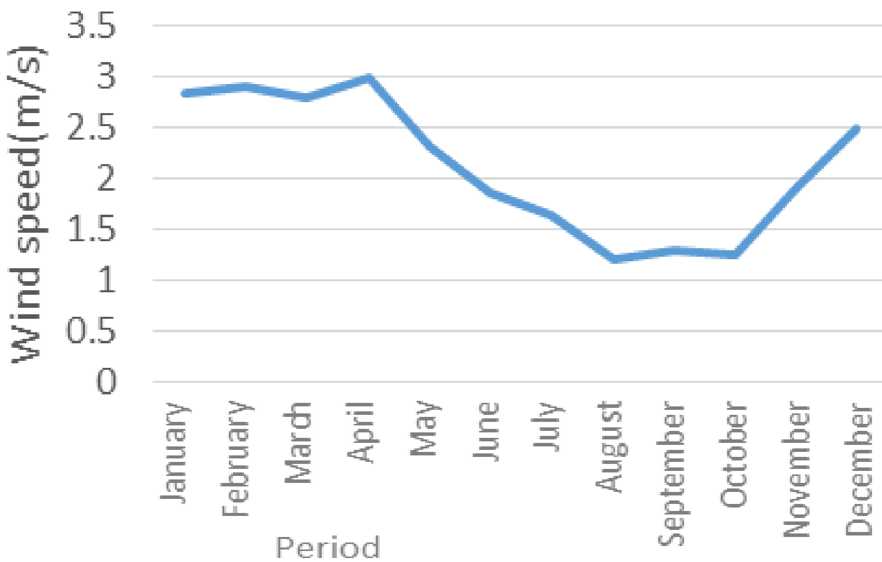

Figure 2. Monthly variation of daily average wind speed.

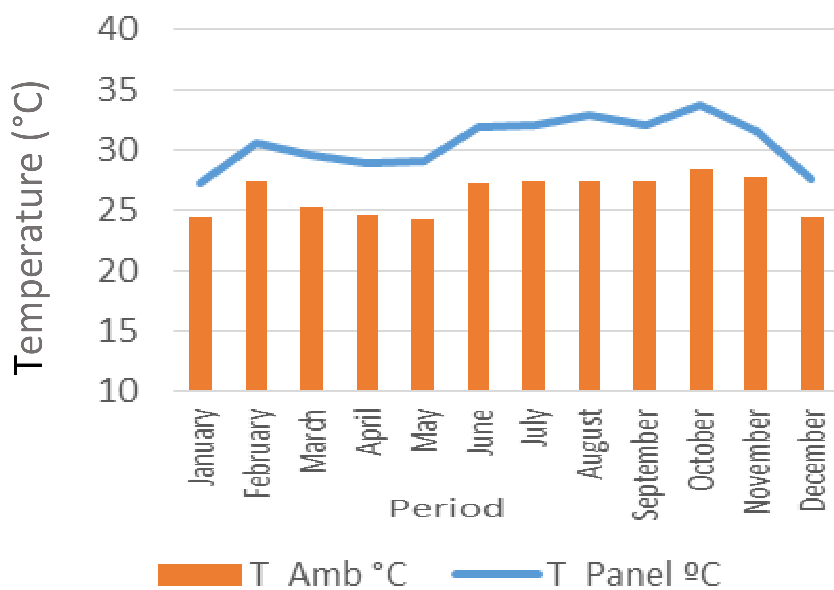

Figure 3. Monthly variation of daily average module temperature and ambient temperature.

Figure 4 shows the monthly variation of daily average insolation and the total monthly energy production of the PV modules. Insolation variations range from a minimum of 151,332 kWh/m^2 in July to a maximum of 219,522 kWh/m^2 in March. However, the monthly variation in the sum of the energy produced follows the same trend as the irradiation and reaches a maximum of 3299.287 MWh in March and a minimum of 2480.723 MWh in July. The months of June, July and August are characterized by a decrease in insolation and energy production due to dust deposition, cloud passages and high temperatures during this period.

Figure 5 shows the variation in average monthly daily yields. The array yield varies in parallel with the final yield, with both yields reaching a maximum value in March (4.63 kWh/kWp/day for the array yield and 4.55

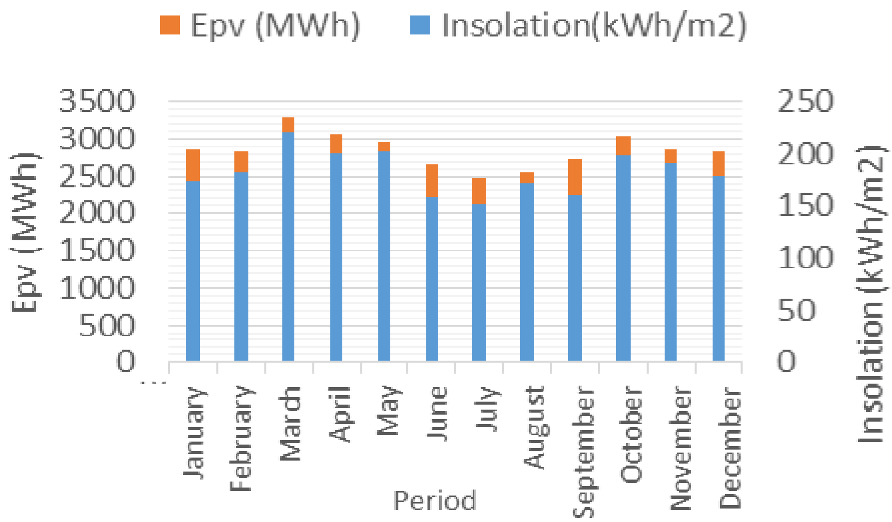

Figure 4. Monthly variation of daily average insolation and the monthly total energy output from PV modules.

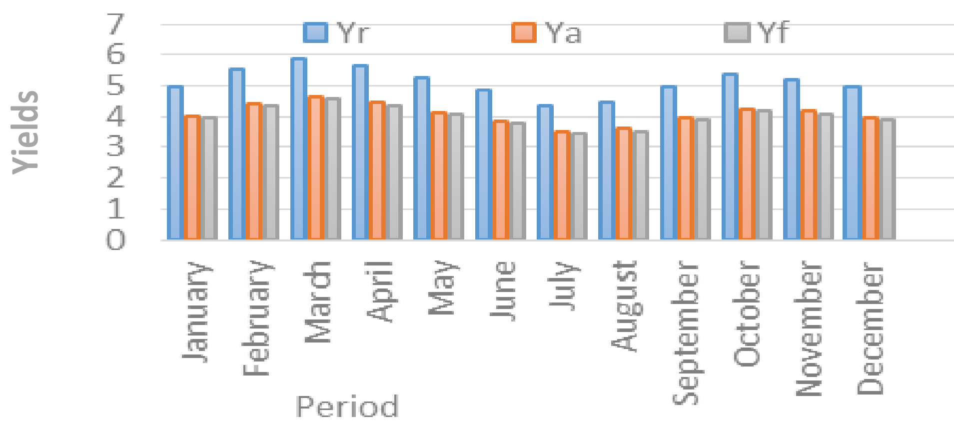

Figure 5. Variation of the monthly average daily yields.

kWh/kWp/day for the final yield) and a minimum value in July (3.48 kWh/kWp/day for the array yield and 3.42 kWh/kWp/day for the final yield). The reference yield ranges from 5.89 kWh/kWp/day in March to 4.37 kWh/kWp/day in July. The months of June, July and August show a reduction in yield due to the decrease in irradiation.

The monthly variation in the average daily capture and system losses is as shown in Figure 6. Capture losses recorded a maximum of 1.262 kWh/kWp/day in March and a minimum of 0.89 kWh/kWp/day in July, while system losses varied from a maximum of 0.076 kWh/kWp/day in March to a minimum of 0.063 kWh/kWp/day in July.

The performance ratio is as shown in Figure 7 and ranges from 0.773 in March to 0.788 in January. The annual value is 78%. Figure 8 shows the capacity factor. It has a maximum value of 19% in March and a minimum

Comparison with PV system in other countries

The final yield (Y_f) and the performance ratio are essential parameters for comparing PV systems. Here, the final yield, capacity ratio and performance factor obtained from this study with performance results from other studies around the world were compared. In Morocco, the final annual yield recorded a value of 4.45 kWh/kWp/day close to that of this study (Attari et al., 2016), however, Kuwait (4.5 kWh/kWp/day) (Al-Otaibi et al., 2015) and Spain (3.8 kWh/kWp/day) (Sidrach de Cardona and Mora Lopez, 1999) found lower values than

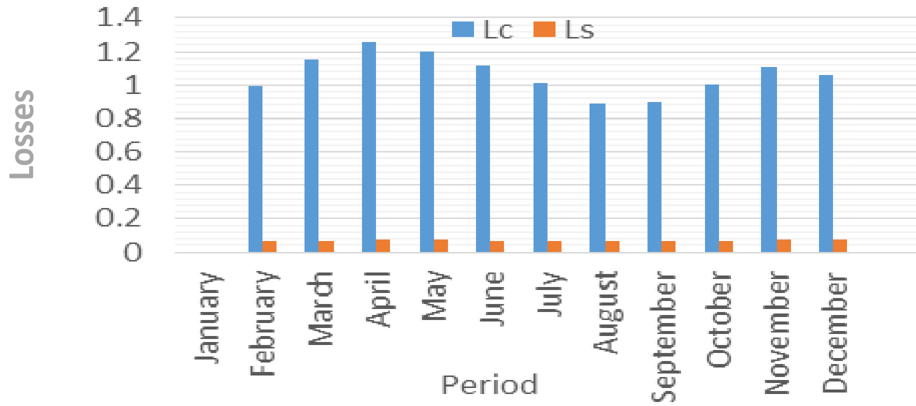

Figure 6. Monthly variation of daily average capture and system losses.

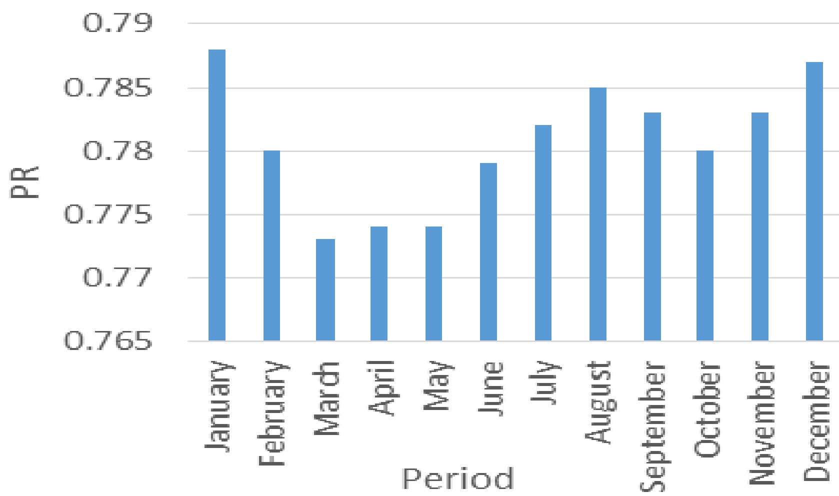

Figure 7. Performance ratio.

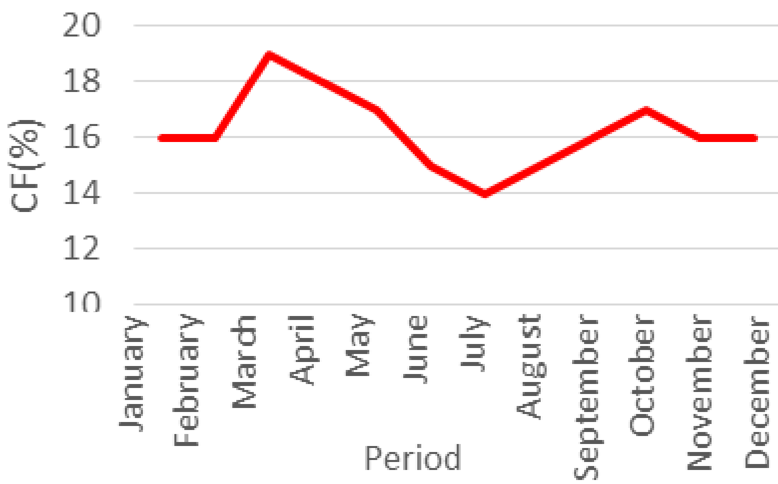

Figure 8. Capacity factor.

that obtained in this study. In India, the final yield is lower than in this study (Padmavathi and Daniel, 2013). Norway 2.55 kWh/kWp/day (Adaramola and Vågnes, 2015). In Mauritania (Elhadj Sidi et al., 2016), the performance ratio of two PV array are 19.54% (array1) and 17.75% (array17), the first value is higher than that obtained in this study while the second is very close to our value. In Crete, the performance ratio is lower than in this study (Kymakis et al., 2009). In Morocco, the performance ratio is higher than in this study (Attari et al., 2016).

This result is in line with expectations due to the high solar potential and the longer sunshine duration in Senegal.

Diass has a hot and dusty climate in the desert, these environmental conditions have an impact on the performance of the site. According to the results of this study, the performance of such a system also depends on the climatic conditions of the installation site.

Conclusion

In this paper, a PV system connected to the 23 MWp grid in Diass, Senegal was monitored throughout 2020 and its performance was evaluated daily.

The annual average daily final yield, baseline yield and grid yield in this study was 4, 5.13 and 4.07 kWh/kWp/day, respectively. The total energy output of the PV modules was found to be 34161 MWh. The energy variation depends on the irradiance. The annual performance ratio and capacity factor are 78 and 16%, respectively. The result of this study is compared with other studies worldwide. The result shows that the system losses depend on the environmental conditions of the site installation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors thank Mr. Bara NDIYAE from SENELEC for giving access to the PV plant data.

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