IJESRT: 10(1), January, 2021 ISSN: 2277-9655

International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

RESEARCHERID
THOMSON REUTERS

[DIOUF *et al.*, 10(1): January, 2021]
ICTM Value: 3.00

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

ANALYSIS PERFORMANCE OF LARGE SCALE GRID CONNECTED PHOTOVOLTAIC POWER PLANTS IN THE TROPICAL REGION

Mame Cheikh DIOUF[1], Mactar FAYE[*1,2], Ababacar THIAM[1,2] , Alphousseyni NDIAYE[1,2] & Vincent SAMBOU[2]

[1] Efficiency and Energetic Systems Research Group, Alioune Diop University, Bambey, Senegal
[2] Laboratoire Eau, Energie, Environnement et Procédés Industriels (LE3PI), Université Cheikh Anta Diop

DOI: https://doi.org/10.29121/ijesrt.v10.i1.2021.5

ABSTRACT

The main objective of this research is analysed and compared the performance of two solar power plants to identify the possible operational problems in the tropical region. The grid connected PV power plants considered in the present study, Ten Merina and Senergy, were installed in the region of Thies (Senegal). Solar power plants have the same installed capacity 29.491 MWp. A period of one operation year of the solar power plants is considered, starting from January 2018 to December 2018. The performance parameters developed by the International Energy Agency (IEA) are used to analyse the performances of solar power plants. The results show that the plane of array irradiance at the sites is identical with an annual average of 6.2 kWh/m^2/d. The annual average performance ratio and final yield of solar power plants are respectively 74.3 %; 4.61 kWh/kWp to Ten Merina and 75.9 %; 4.66 kWh/kWp to Senergy. These results are compared to other solar power plants installed in different locations around the world.

KEYWORDS: Photovoltaic; performance analysis; grid-connected; solar power plant; tropical region.

1. INTRODUCTION

Large scale grid-connected PV power plants is an essential part of the electric power generation sector in Senegal. In 2007, the total installed PV capacity in Senegal was 2 MWp. This capacity has grown exponentially, from 113 MWp in 2017. From today's levels, the total installed PV capacity could grow almost two fold over the next years, reaching a capacity of to 255 MWp by 2020 [1]. The optimal operation of solar power plants throughout their lifetime is the main challenge to ensure rapid return on investment and economic viability.

The operation of solar power plants can be affected by environmental effects and malfunction of components [2]. Nevertheless, an evaluation of the recent achievements of large scale grid-connected PV power plants in Senegal should be carried out before pursuing the strategy of their development. In order to study the generated production results of a solar power plant, it is necessary to evaluate the performance of the most important factors, such as geographic location and climatic condition, characteristics of components, accumulation of dust and temperature of PV modules [3]. These various factors mentioned affect the performance of solar power plants [4]. The evaluation of these different factors allows to know the short and long term performance of a solar power plant. It helps identify operation problems of solar power plants in order to perform cost-effective maintenance [5]. After identifying the operational problems that might arise due to solar power plant, different strategies that can mitigate these problems. As a result, several authors have been interested in evaluating the performance of grid-connected solar power plant.

Micheli et al. [6] analysed and compared the actual performance of two solar PV grid-connected systems named CTB and Q2, in northern Italy, with a power of 15.9 kWp and 17.94 kWp. The results are presented for the period from 15 October, 2011 to 14 October, 2012. Analysis of climatic data shows that the two solar PV systems operated most of the time with average irradiance values lower than those defined by standard conditions. The operating temperatures of the modules are higher than the temperature under standard conditions. The performance ratio values calculated for the whole year are 89.1% for the CTB system and 82.7 % for the Q2, which confirms the good quality of the modules and their installation.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Milosavljević et al. [7] presented the basic data and the equipment for the estimation of performance and energy efficiency on a 2 kWp solar PV system installed in Serbia. The results are presented for the period 01 January, 2013 to 01 January, 2014. It is showed the increase in ambient temperature causes a decrease in the energy efficiency of the solar PV system. The annual average value of the performance ratio was 93.6 %.

Adaramola and Vagnes [8] examined the performance of a 2.07 kWp solar PV system in Norway. The results presented are based on data recorded from March 2013 to February 2014. Power generation follows the same trend as illumination in the plan. Energy production for the months of November to February (winter period) is generally low. The energy production of this winter period was affected by low illumination in the plan, a reduction in the number of hours of sunshine per day and losses due to soiling. These factors also cause low returns and affect the performance of the system during these months.

Ayompe et al. [9] evaluated the performance of a grid-connected 1.72 kWp solar PV system in Dublin, Ireland. The system was monitored between November 2008 and October 2009. The low levels of sunshine during the winter resulted in low final yield. But in this period the energy losses of the system are so low which generates a high performance ratio. Ireland is characterized by low irradiance levels. However, the high average wind speed and low ambient temperature give the latter a favourable climate for PV energy production.

A Al-Otaibi et al. [10] presented the first performance evaluation of two grid-connected thin-film solar PV systems in Kuwait of different power 85.05 kWp and 21.6 kWp. Data was collected from January to December 2014. The highest energy yields for both sites were reported in July corresponding to a period of heavy solar irradiation, sandstorms and increasing average wind speed. It appears from this work that the weekly automated cleaning was sufficient to maintain good performance with less than 1.7 % soil loss per week.

Dobaria et al. [11] examined an analytical performance evaluation of a grid-connected 5.05 kWp solar PV system installed in Rajkot, India. The parameters of the system was monitored for 3 years. The drop in yields during the months of June to August is due to low solar radiation. This period is marked by the rainy season corresponding to cloudy days reducing the number of hours of sunshine. The performance ratio was low for the months April through July due to temperature and high soiling.

Attari et al. [12] presented the evaluation of a grid-connected 5 kWp solar PV system installed in Tangier, Morocco. Experimental data was recorded from 01 January, 2015 to 30 December, 2015. Energy production for the summer period is low. This production for these months was affected by the reduction in the number of hours of sunshine due to the amount of cloudy weather during this time of year. The yield values observed for the months of December and February are low due to the low irradiation during these months. Significant losses can be observed in the summer due to dirt, dust and the lack of scheduled maintenance during this period.

Dabou et al. [13] analysed the effect of weather conditions on the performance of grid-connected solar PV systems installed in the Saharan region of southern Algeria for the year 2010. The experimental results show that the rapid evolution of solar irradiance due to the variation of cloud or storm cover influences the performance and stability of the solar PV system. The analysis shows that the minimum value of solar PV system yields correspond to sandstorm days, due to the low level of daily solar irradiation. The minimum value of performance ratio and efficiency of PV module, system and inverter, as well as system losses were in clear weather due to high ambient temperature.

The research papers presented above show that the performance analysis of solar PV systems has been the subject of several studies in different countries around the world. The results obtained in this literature review demonstrate that performance of solar PV system are highly dependent upon on locations and varies according to their climatic and weather condition. To our knowledge, the available literature provides scarce information on the actual operation and performance from solar power plant in the tropical region such as Senegal. This tropical region have specific climate and weather condition compared in different locations around the world. The objective of this article is to compare and analyse, within the framework of Senegal, the actual performances of two solar power plants and their yearlong evolution. The results from this study allow to know the possible operational problems

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

of solar power plants for this location and locations with similar climate conditions. Furthermore, the findings can be used in validating models that estimate the performance of solar power plant in the tropical region.

2. COMPONENTS OF SOLAR POWER PLANTS

In order to study the performance of a large scale grid-connected photovoltaic power plants, it is necessary to list its different components. It mainly consist of PV arrays, inverters, transformers [14] [15]. Their energy production is affected by the performance of the various components [16].

- PV arrays

Photovoltaic modules generate electrical energy from incident sunlight making use of the photovoltaic effect [17]. Several modules are connected in series to form a string, and a number of strings are paralleled and connected to an inverter [18]. The strings of PV modules are connected to the inverter by means of a junction box to oppose the reverse current flow in a string.

- Inverters

The inverter is a major component of solar PV systems and affects the overall performance of the PV system [19]. In the case of large scale grid-connected photovoltaic power plants, the PV modules generate direct current and are connected to a PV inverter to generate alternating current. The connection of PV inverters with modules determines the topologies of the solar power plant [20]. Surge protection devices protect each inverter from input and output surges resulting. A series of circuit breakers protect the AC lines in accordance with normal electrical design practice [21].

- Transformers

Grid-connected photovoltaic systems use transformers to provide galvanic isolation, increase voltage, and transfer energy to the utility grid [22]. Distribution and substation transformers are the types of transformers installed in solar power plants. Distribution transformers are used to step up the inverter output voltage for interconnection to the utility grid. Substation transformer step up the MV of solar power plant to an appropriate interconnection voltage to interconnect to the utility grid at transmission voltage levels above 35 kV [23].

3. DESCRIPTION OF SOLAR POWER PLANTS

3.1 Site characteristics and solar radiation

The two solar power plants, Ten Merina and Senergy, are located in the region of Thies (Senegal). The Ten Merina solar power plant is located in Merina Dakhar, between 16.35° West longitude and 15.09° North latitude. On an area of 83 ha, it occupies only 46 ha of this area for its establishment. The Senergy solar power plant is located in Santhiou Mekhe, between longitude 16.40° West and latitude 15.07° North latitude. The surface area of the Senergy solar power plant site is 64 ha. Fig.1 shows the geographical location of the region of Thies (Senegal).
The location of the sites is characterized by two seasons: a dry season from November to June and a rainy season from July to October. The solar potential in this tropical region are characterized with an annual average sunshine duration of about 3000 hours and an average overall daily solar radiation of 5.7 kWh/m^2/d [24].

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

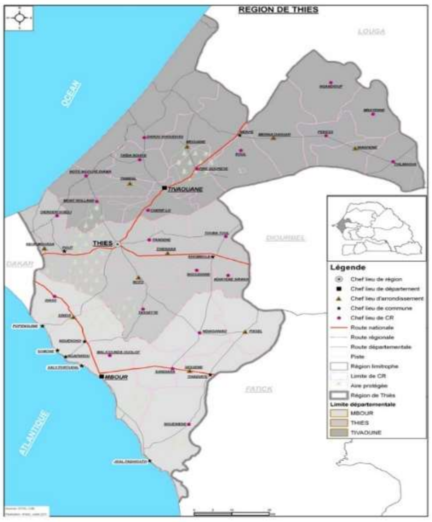


***Figure 1**: Geographic location of Thies, Senegal* [25]

3.2 PV arrays

With the same installed capacity of 29.491 MWp, comprising 92,160 modules, solar power plants have the same design configuration. For both PV systems, the PV array is divided into 12 tranches of 7,680 modules. The unit power of the PV modules is 320 Wp corresponding to the power measured under STC. However, the solar power plants have a power limitation of 20.3 MW for Senergy and 20.1 MW for Ten Merina in order to meet the power requirements injected to the utility grid.

For both PV systems, the modules are installed on galvanized steel supporting structures with an inclined plane at 15 degrees from the horizon and oriented due south in order to optimize energy production. Fig.2 shows the layout of the modules on the PV array of solar power plants. The Ten Merina solar power plant, the modules used are from JINKO SOLAR type JKM320PP-72. The Senergy solar power plant uses solar modules from RENESOLA of the type JC320-24/Abs. The technical specifications of modules are given in Table1.

For both PV systems, the modules are connected to each other to obtain a chain of 20 modules. For Senergy, a group of 16 strings of modules are connected in parallel and connected to a junction box corresponding to a PV subfield. The 08 junction boxes of the PV subfield are connected to an inverter for the conversion of direct current to alternating current. Senergy are equipped with 288 junction boxes.

For Ten Merina, a group strings of modules is connected in parallel and connected to a junction box corresponding to a PV subfield. There are groups of 15 and 12 strings. The junction boxes with 15 strings are at 288 and the junction boxes with 12 strings are at 24. Ten Merina are equipped with 312 junction boxes.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

a) Ten Merina *b) Senergy*

Figure. 2: Layout of modules of solar PV power plants

3.3 Inverter transformer station (ITS)

Inverter transformer stations convert LV/MV power via 50 Hz three-phase inverters and transformers. These stations are isolated from external heat and dust deposits to ensure the proper functioning of the equipment. Solar power plants are equipped with 12 ITS on each site. ITS are largely made up of :

- Inverters :

Each ITS is equipped with 03 inverters of 680 kW power from the manufacturer Schneider, and of the Conext Core XC-680 type. The number of inverters at each site is 36. The inverters are limited to a power of 558 kW for the Ten Merina and 562 kW for that of Senergy. The 03 inverters of each ITS are coupled to a transformer.

- Transformer :

The conversion LV/MV is ensured by a transformer in each ITS. The nominal power of the transformer is 2 MVA. The number of transformers on each site is 12. The transformers are looped through groups of 06 on two 30 kV transmission lines.

Table 1. Specification of modules used of solar PV power plants

	Ten Merina	Senergy
Trademark	JINKO SOLAR	RENESOLA
Model	JKM320PP-72	JC320-24/Abs
Cells type	Crystalline polysilicium	Crystalline polysilicium
Number of cell	72	72
Maximum power at STC	320W	320W
Maximum power point voltage (Vmp)	37.4V	37.4V
Maximum power point current (Imp)	8.56A	8.56A
Open circuit voltage (Voc)	46.4V	45.6V
Open circuit current (Isc)	9.05A	9A
Module efficiency	16.49%	16.48%
Length	1956 mm	1956mm
Widght	992 mm	993mm
Weight	26.5kg	27kg
Temperature Coefficient Pmax	-0.40%/°C	-0.40%/°C

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

3.4 Delivery station

The delivery station is installed to begin the process of sending power to the utility grid. It is located within the enclosure of the solar power plant and including the following main pieces of equipment, 30kV switchboard, metering. There are 02 transmission lines at each site for the delivery the energy produced to the high voltage substation at 30/90 kV. In Fig 3 a schematic representation of the considered solar power plants is presented.

3.5 Measurement and data acquisition system

To control the production and facilitate maintenance, solar power plants are equipped with energy meters, weather stations, radiation sensor, and data acquisition system. In Fig.4 is shown weather station and pyranometric sensor. Weather and radiation data are collected from different locations on the solar power plants. The data is automatically recorded by a data acquisition system. This system is a complete SCADA (Supervisory Control and Data Acquisition) which allows the operator to control the operation of the solar power plants.

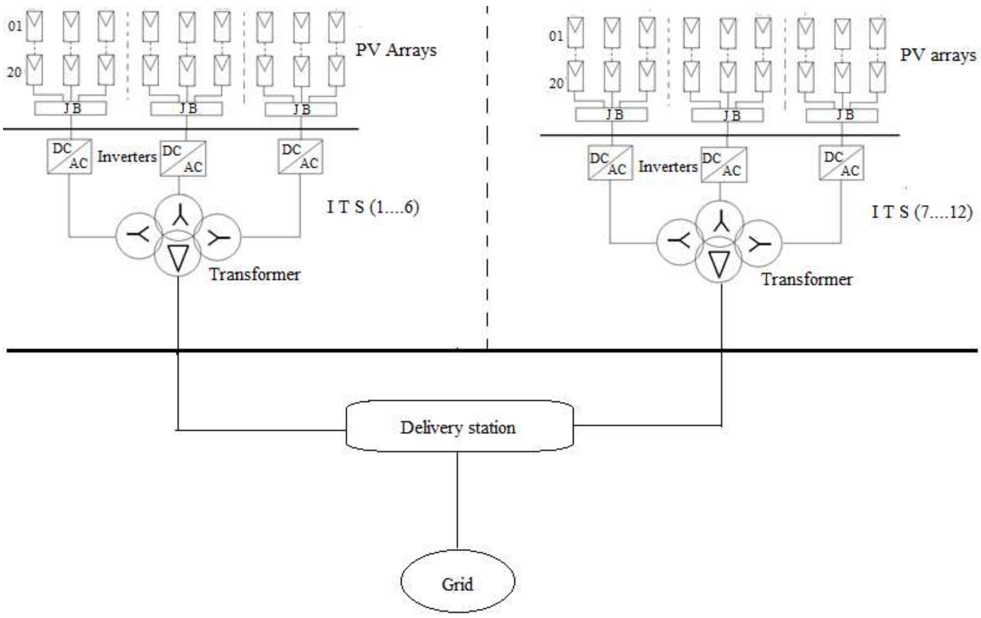


Figure 3: Schematic representation of the considered solar PV power plants

a) Weather station *b) pyranometric sensor*

Figure 4: Measuring data systems of solar PV power plants

4. PV SYSTEM PERFORMANCE PARAMETERS

The performance parameters used in this study are the ones developed by International Energy Agency (IEA). Some derived parameters related to energy and performance were calculated using the monitoring data recorded : energy generated (E_{AC}), final yield (Y_F); reference yield (Y_R), performance ratio (PR), capacity factor (CF), efficiency of the solar system ($\eta_{sys,m}$) [9], [26], [27], [28].

- energy generated E_{AC}

Energy generated is defined as the amount of alternating current (AC) produced by the power plant over a given period of time. The total monthly energy $E_{AC,m}$ generated by the solar PV system is given by Eq. (1) :

$$E_{AC,m} = \sum_{d=1}^{N} E_{AC,d} \quad \text{(E1)}$$

- final yield (Y_F)

The final yield, is defined in Eq. (2), and indicates the ratio between the energy E_{AC} in kWh and the maximum power P_{PV} en kWp of the solar PV system under standard test conditions (1000 W/m² and 25°C). This quantity represents the number of hours that the PV array should operate at its rated power.

$$Y_F = \frac{E_{AC}}{P_{PV}} \quad \text{(E2)}$$

- reference yield (Y_R)

The reference yield, is calculated using Eq. (3), and represents the ratio between the quantity of solar radiation expressed in kWh/m² and the reference radiation, 1000W/m². This parameter represents the number of hours during which the illumination is equal to the reference one.

$$Y_R = \frac{E_t({kWh}/{m^2})}{1({kW}/{m^2})} \quad \text{(E3)}$$

- performance ratio (PR)

The performance ratio (PR) represents the ratio of the energy injected into the network (final yield) over the energy that the system could have produced if it had operated under its nominal conditions (STC) of 1 kW/m^2(reference yield), as shown in Eq.(4). When the PR value approaches the maximum, it shows a high performance solar PV system. According to European PV directives, a good PR value is between 80-85% and a value below 75% indicates a problem with the solar PV system [29].

$$PR = \frac{Y_F}{Y_R} \quad \text{(E4)}$$

- capacity factor (CF)

The capacity factor (CF) is defined as the ratio between the actual annual energy production of the PV installation and the amount of energy it would generate if it were operated at full rated power for 24 hours per day for year, as shown in Eq. (5). The typical capacity factor of a solar PV system is between 15 % and 40 % [30]. Therefore, the capacity factor is a very important parameter for evaluating a grid connected solar PV system.

$$CF = \frac{E_{AC,a}}{P_{PV} \times 8760} \quad \text{(E5)}$$

- efficiency of the solar power plant

The energy performance of solar power plant depends on the overall efficiency of the equipment used in these systems, is calculated using Eq. (6). The efficiency of the solar PV plant is calculated as the ratio between the energy produced over solar radiation and the area of the modules.

$$\eta_{sys,m} = \frac{E_{ACd,m}}{Aa \times E_t} \quad \text{(E6)}$$

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

5. RESULTS AND DISCUSSION

Fig. 5 shows monthly average accumulated POA irradiance for sites. The POA irradiance from the Ten Merina site varies between 5.5 kWh/m^2/d in November and 7.2 kWh/m^2/d in April with an annual average of 6.20 kWh/m^2/d. The Senergy site, POA irradiance varies between 5.5 kWh/m^2/d in July and 7.1 kWh/m^2/d in April with an annual average of 6.16 kWh/m^2/d.

The lowest values of the POA irradiance are found within the rainy season to the Ten Merina and Senergy sites. The highest values of solar radiation occur during the dry season. This decrease in the value of POA irradiance within the rainy season can be explained by the fact that most days are cloudy, reducing the number of hours of sunshine over this period. The POA irradiance is almost identical for both sites in the year. The implantation sites are characterized by high levels of solar.

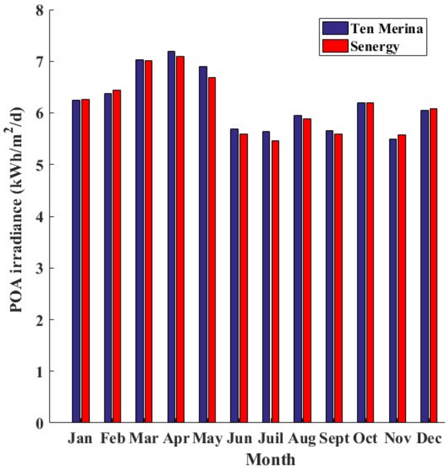


Figure 5: POA irradiance at Ten Merina and Senergy

Fig. 6 shows variation of energy generated against POA irradiance. It is seen that energy generated have a linear relationship with POA irradiance. The correlation coefficients are 0.6747 for Ten Merina and 0.6679 for Senergy. The correlation coefficients are low, which means that solar power plants presented production faults. The monthly correlation coefficients are given in Table2.

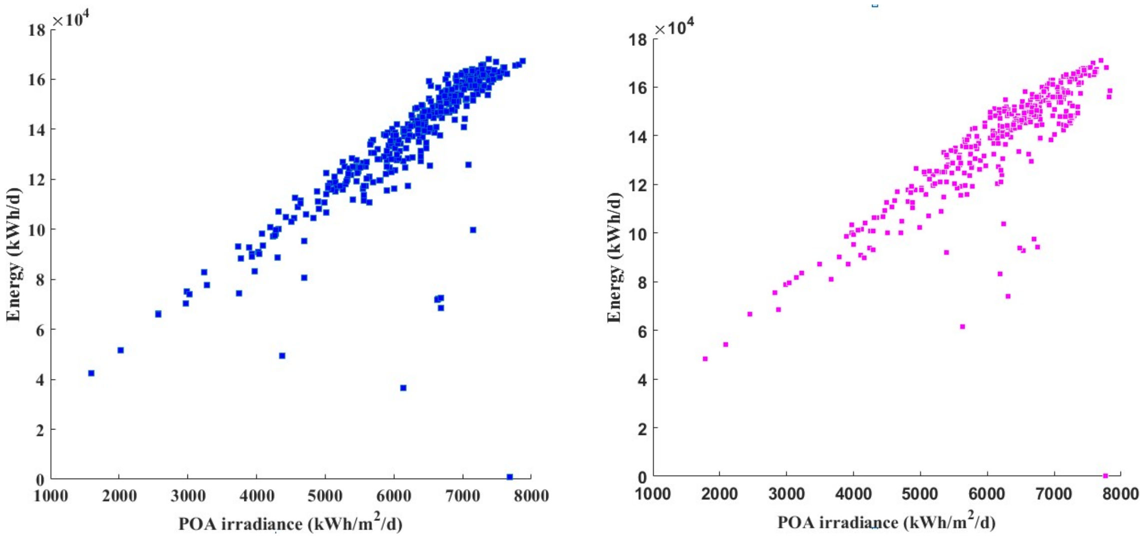
Fig. 7 shows the monthly specific energy of solar PV plants which is the generated energy divided by the installed PV capacity. The specific energy by the Ten Merina plant varies between 120.4 kWh/kWp in June and 162.0 kWh/kWp in April, with an annual average of 140.2 kWh/kWp. For the plant Senergy, it varies between 129.0 kWh/kWp in September and 159.0 kWh/kWp in May, with an annual average of 141.7 kWh/kWp.

The specific energy minimums of Ten Merina and Senergy are obtained in June and November respectively. The coefficients for these two months, June (0.8894) and September (0.8126), show that the decrease in these productions is not linked only to a reduction in the POA irradiance.

The lowest coefficient is noted in March for these two solar power plants. This is explained, the date of 10 March corresponds to a day during which the solar power plants have been shut down for maintenance. The month of April shows the most POA irradiance, the power plants generate good energy production. However, with the limitation of the power of solar power plants, the performance is reduced which reduces the drop in coefficients. This drop in energy production is more significant with the Senergy solar power plant.

For the Ten Merina solar power plant, the correlation coefficient is low in January (0.4983) marking the 06 days of under production for that month. A day of production under is also noted in October giving this month a coefficient of 0.7556.

The decoupling from the grid following rain in September make a drop in production to Senergy plant. A fault on a transmission line in December caused a decrease in the operation of this Senergy plant for 06 days.



a) Ten Merina ***b) Senergy***

Figure 6: Energy generated against POA irradiance

Table 2. Monthly correlation coefficients

	Jan	Feb	mar	Apr	May	Jun	Juil	Aug	Sept	Oct	Nov	Dec
Ten Merina	0.4983	0.9516	0.3643	0.8202	0.9084	0.8894	0.9794	0.9892	0.9802	0.7556	0.9854	0.9684
Senergy	0.9768	0.9627	0.3940	0.7708	0.9551	0.9244	0.9863	0.9873	0.8126	0.9815	0.9927	0.6588

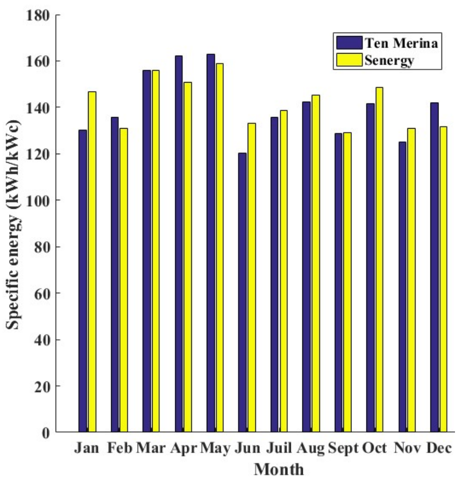


Figure 7: Specific energy of solar power plants

Fig. 8 shows yield final and reference of solar power plants. The yield final of the Ten Merina plant varies between 4.0 kWh/kWp in June and 5.4 kWh/kWp in April, with an annual average of 4.61 kWh/kWp. For the Senergy plant, it varies between 4.2 kWh/kWp in December and 5.1 kWh/kWp in May, with an annual average of 4.66 kWh/kWp.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

The yield reference of the Ten Merina plant varies between 5.6 kWh/kWp in July and 7.2 kWh/kWp in April, with an annual average of 6.21 kWh/kWp. For the Senergy plant, it varies between 5.2 kWh/kWp in July and 7.2 kWh/kWp in April, with an annual average of 6.16 kWh/kWp.

The lowest energy yield values are observed in the rainy season which is between the months of June to September. The values observed between March and May are higher than the values in other periods due to the higher solar radiation.

Fig. 9 shows the variation of the monthly capacity factor of solar power plants. This factor is the index that shows the amount of time as a percentage that the output of the solar power plants is operating at its highest capacity. The capacity factor Ten Merina plant varies between 13.7 % in June and 18.6 % in May with an annual average of 16.0 %. For the Senergy plant, this factor varies between 14.2 % in September and 18.2 % in May with an annual average of 16.2%. Therefore, the solar PV plants in this study only produce nominal power in 1402 h or about 58 days in the year to Ten Merina and in 1419 h or about 59 days in the year to Senergy.

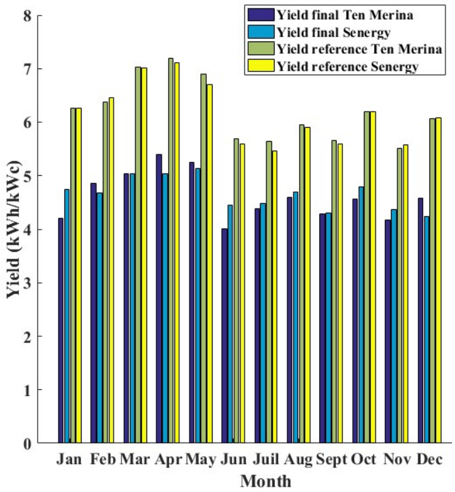


Figure 8: Yield reference and final

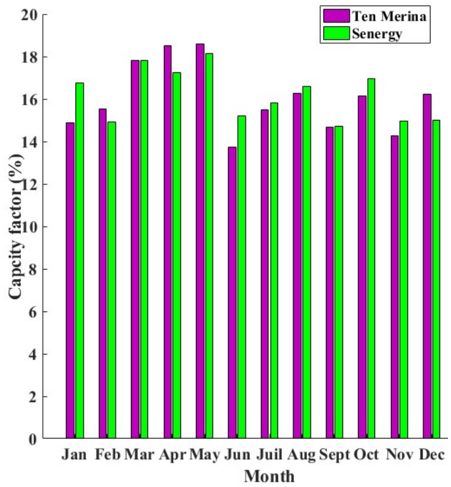


Figure 9: Capacity factor

Fig. 10 and Fig. 11 illustrate the ratio performance and efficiency of solar PV plants. It is observed that the highest values of performance and efficiency of Ten Merina plant were obtained in July with respective values 77.6 % and 12.8 % and the lowest values in January 67.2 % and 11.1 %. The highest values of performance ratio and energy efficiency of Senergy plant were obtained in July with respective values 81.9 % and 13.5 % and the low values in December 69.7 % and 11.5 %. The annual average performance ratio and efficiency of solar power plants are respectively Ten Merina 74.3 %; 12.3 % and Senergy 75.9 %; 12.5 %.

A reduction in the performance ratio and efficiency of solar power plants is observed in the months of November to June. These periods correspond to the dry season marked by an absence of precipitation. The intensity of dust caused by human and natural activities is expected to increase due to the decrease in precipitation during these periods [31]. We can deduce that this absence of precipitation during these periods give accumulation of dust on the module. Therefore, it decreases the performance of solar power plants.

The highest values of performance ratio and efficiency of solar power plants were observed in July and August. These periods marked by low POA irradiance, due to the rainy season. This confirms a reduction efficiency and performance ratio performance ratio of solar PV systems is observed in the occurrence of times with high values of solar irradiance [32].

This analysis of performance ratio and efficiency emphasizes the importance of choosing an efficient cleaning strategy to reduce the adhesion of dust on the modules for maximum profitability of solar power plants.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Tab 3 shows some performance parameters for other systems installed in different locations around the world. For a comparison study of solar PV systems to other systems, the final yield and the performance ratio are used more because they are independent of the capacity of the installed PV system [9].

Comparison of the results of this study with those obtained in other international studies revealed that the final yield results of Ten Merina (4.61 kWh/kWp/d) and Senergy (4.66 kWh/kWp/d) are superior to those of other similar studies in Europe; Ireland (2.41 kWh/kWp/d); Norway (2.55 kWh/kWp/d) .This trend is expected due to higher solar irradiation and longer hours of sunshine in the tropical region compared to Europe. The yield final of the two solar PV plants are decreasing to the systems revenues from desert conditions for example Oman (5.1 kWh/kWp/d) and South Africa (4.96 kWh/kWp/d). These desert regions marked by a high rate of sunshine throughout year which explains the important values of the final yield.

The yield final of Ten Merina and Senergy are similar to the yield final of solar power plants located in the tropical region, for example in Brazil (4.6 kWh/kWp/d); Morocco (4.45 kWh/kWp/d); in Mauritania (4.27 kWh/kWp/d); in India (4.81 kWh/kWp/d) and Djibouti (4.6 kWh/kWp/d).

Based on this comparison, all studies showed good performance except systems located in Mauritania 67.96 %; Suriname 74.5 % and Ten Merina 74.3 %.

The final yield and the performance ratio of the Ten Merina and Senergy meet expectations due to the significant solar potential in Senegal. However, these performance parameters can be improved upon results of optimistic studies on factors affecting the performance of solar power plants.

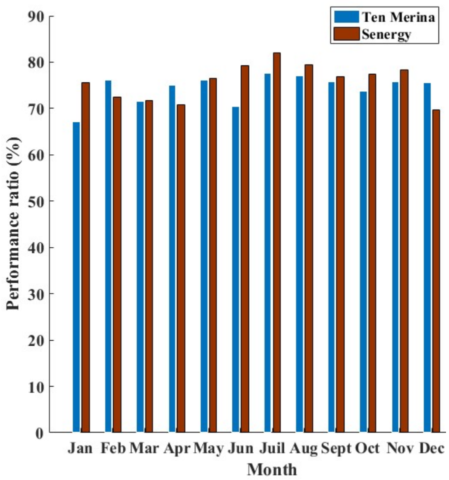


Figure 10: Performance ratio

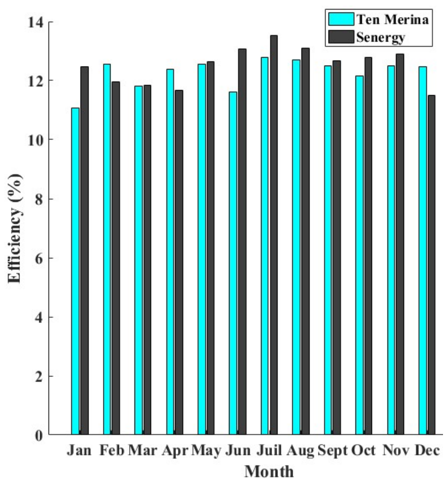


Figure 11: Efficiency of solar PV plants

Table 3. Compared performance parameters for other systems installed in different locations

Location	Capacity (kWc)	Period	Yf (kWh/kWc/d)	RP (%)	Reference
Ireland	1.72	Nov 2008 - Oct 2009	2.41	81.5	[9]
Norway	2.07	Mar 2013 –Fev 2014	2.55	83.03	[8]
India	5000	May 2011-Apr 2012	4.81	89.15	[33]
Malaysia	3	Oct 2013- Mar2014	3.8	77.28	[34]
Oman	1.4	Jan2013–Jun 2013	5.1	84.6	[30]
Morocco	5	Jan 2015-Dec 2015	4.45	79	[12]

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Djibouti	300	Fev2012 - Dec 2013	4.6	85	[27]
South Africa	3.2	Jan 2013-Dec 2013	4.9	84.3	[35]
Mauritania	954.72 (Array1)	01 Sep 2014 -31 Aug 2015	4.27	67.96	[36]
Brazil	2.2	Jun 2013-May 2014	4.6	82.9	[37]
Suriname	27	Apr 2015–Mar 2016	3.7	74.5	[38]
Ten Merina	29491	Jan 2018-Dec 2018	4.61	74.3	Present study
Senergy	29491	Jan 2018-Dec 2018	4.66	75.9	Present study

6. CONCLUSION

The actual performance results of two large scale grid-connected photovoltaic power plants were analysed and compared over the period from January 2018 to December 2018. The results show the implantation sites in the tropical region are characterized by high levels of solar radiation giving them a favourable climate for energy production. Solar PV power plants concentrate the highest values of energy produced during dry season from March to May. The lowest values of the energy produced were recorded during the rainy season from June to September. Energy generated have a linear relationship with POA irradiance, the decrease in the value of energy produced by solar power plants inside the rainy season can be explained that most days are cloudy, reducing the number of sunny hours during this period. The low correlation relationship between energy production and POA irradiance shows undistributed energies and production faults by the two solar power plants linked maintenance works, malfunction of components and accumulation of dust on PV arrays.

The lowest energy yield values are observed during the rainy season which is between the months of June to September. The values observed between March and May are higher due the higher solar radiation. The highest values of performance ratio and efficiency of solar power plants were observed in July and August marked by low solar radiation.

These results compared to other systems installed in different locations around the world meet expectations due to the high solar potential. It is therefore concluded that the current climatic conditions and the design of solar power plants are suitable for good PV energy production. In view of these comparison results of the two solar power plants, there are crucial requirements to be corrected to obtain the good performance throughout their lifetime. Comprehensive PV module cleaning studies and continuous monitoring are needed to quickly resolve solar power plant failures and production faults.

7. ACKNOWLEDGMENTS

Ten Merina SA and Senergy PV SA are kindly acknowledged for providing the information regarding the plants under study.

NOMENCLATURE

A_a: surface of the modules (m^2)
AC : alternating current
CF: capacity factor (%)
d : day
DC : direct current
E_{AC}: energy produced (kWh)
E_t: solar radiation (kWh/ m^2)
ha: hectare
IEA : International Energy Agency

ITS: Inverter Transformer Station
k : kilo
LV : Low voltage
M : mega
m : month
MV: Medium voltage
m²: square meter
N: number of days in the month
n_{sys}: system efficiency (%)
POA : Plane of array
PR: performance ratio (%)
PV : photovoltaic
P_{PV} : Installed power (kWp)
STC : standard test conditions
V : volt
Wh : Watt hours
Wp : Watt peak
Y_F: final yield (kWh/kWp)
Y_R: reference yield (kWh/kWp)

REFERENCES

[1] A. S. BA, «The energy policy of the Republic of Senegal : Evaluation and Perspectives,» HAL, Université Paris Dauphine, PSL Research University, 2018.
[2] N. Ghaffarzadeh et A. Azadian, «A Comprehensive Review and Performance Evaluation in Solar (PV) here, type the title of your paper, Capitalize first letter of each,» Journal of Solar Energy Research, vol. 4(4), pp. 252-272, 2019.
[3] S. Edalati, M. Ameri et M. Iranmanesh, «Comparative performance investigation of mono- and poly-crystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates,» Applied Energy, vol. 160, p. 255–265, 2015.
[4] M. Díez-Mediavilla, C. Alonso-Tristán, M. Rodríguez-Amigo, T. García-Calderón et M. Dieste-Velasco, «Performance analysis of PV plants: Optimization for improving profitability,» Energy Conversion and Management, vol. 54 , p. 17–23, 2012.
[5] J. Mokri et J. Cunningham, «Metrics and methods to assess performance of existing systems to aid bankability of PV asset class,» chez PV System Performance Assessment, the SunSpec Alliance, 2014.
[6] D. Micheli, S. Alessandrini, R. Radu et I. Casula, «Analysis of the outdoor performance and efficiency of two grid connected photovoltaic systems in northern Italy,» Energy Conversion and Management, vol. 80, p. 436–445, 2014.
[7] D.Milosavljević, D., T.M.Pavlović et D. S. .Piršl, «Performance analysis of A grid-connected solar PV plant in Niš, republic of Serbia,» Renewable and Sustainable Energy Reviews, vol. 44, p. 423–435, 2015.
[8] M. S. Adaramola et E. E. Vagnes, «Preliminary assessment of a small-scale rooftop PV-grid tied in Norwegian climatic conditions,» Energy Conversion and Management, vol. 90, p. 458–465, 2015.
[9] L. Ayompe, A. Duffy, S. McCormack et M. Conlon, «Measured Performance of a 1.72 kW Rooftop Grid Connected Photovoltaic System in Ireland,» Energy Conversion and Management, 2010.
[10] A. Al-Otaibi, A. Al-Qattan, F. Fairouz et A. Al-Mulla, «Performance evaluation of photovoltaic systems on Kuwaiti schools' rooftop,» Energy Conversion and Management, vol. 95, p. 110–119, 2015.
[11] B. Dobaria, M. Pandya et M. Aware, «Analytical assessment of 5.05 kWp grid tied photovoltaic plant performance on the system level in a composite climate of western India,» Energy, vol. 111, pp. 47-51, 2016.
[12] K. Attari, A. Elyaakoubi et A. Asselman, «Performance analysis and investigation of a grid-connected photovoltaic installation in Morocco,» Energy Reports, vol. 2, p. 261–266, 2016.
[13] R. Dabou, F. Bouchafaa, A. H. Arab, A. Bouraiou, M. D. Draou, A. Neçaibia et M. Mostefaoui, «Monitoring and performance analysis of grid connected photovoltaic under different climatic conditions in south Algeria,» Energy Conversion and Management, vol. 130, p. 200–206, 2016.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[14] E. Rakhshani, K. Rouzbehi, A. J. Sánchez, A. C. Tobar et E. Pouresmaeil, «Integration of Large Scale PV-Based Generation into Power Systems: A Survey,» Energies, vol. 12(8), 2019.
[15] P. Han, Z. Lin, L. Wang, G.Fan et X. Zhang, «A Survey on Equivalence Modeling for Large-Scale Photovoltaic Power Plants,» Energies, vol. 11(6), 2018.
[16] A. Ahadi, N. Ghadimi et D. Mirabbasi, «Reliability assessment for components of large scale photovoltaic systems,» Journal of Power Sources , vol. 264 , pp. 211- 219, 2014.
[17] G. M. S. Islam, A. Al-Durra, S. M. Muyeen et J. Tamura, «Low voltage ride through capability enhancement of grid connected large scale photovoltaic system,» chez 37th Annual Conference on IEEE Industrial Electronics Society, IECON, Australia, 2011.
[18] Y. Ding, W. Shen, G. Levitin, P. Wang, L. Goel et Q. Wu, «Economical evaluation of large-scale photovoltaic systems using Universal Generating Function techniques,» J. Mod. Power Syst. Clean Energy, vol. 1(2), p. 167–176, 2013.
[19] F. Vignola, F. Mavromatakis et J. Krumsick, «Performance of PV inverters,» chez American Solar Energy Society, 2008.
[20] A. C.Tobar, E. B.Massagué, M. A. Peñalba et O. G.Bellmunt, «Topologies for Large Scale Photovoltaic Power Plants,» Renewable and Sustainable Energy Reviews, vol. 59, pp. 309-319, 2016.
[21] G. Zini, C. Mangeant et J. Merten, «Reliability of large-scale grid-connected photovoltaic systems,» Renewable Energy , vol. 36 , pp. 2334-2340, 2011.
[22] Á. Roca Rubí, «Design and Modelling of a Large-Scale PV Plant,» Escola Tècnica Superior d'Enginyeria Industrial de Barcelona, 2018.
[23] «Blue Oak Energy,» 2020. [En ligne]. Available: https://www.blueoakenergy.com/blog/distribution-and-substation-transformers-for-utility-solar-p. [Accès le 2020].
[24] A. Ndiaye, C. M. F. Kébé, P. A. Ndiayea, A. Charki, A. Kobib et V. Sambou, «A Novel Method for Investigating Photovoltaic Module Degradation,» Energy Procedia, vol. 36, p. 1222 – 1231, 2013.
[25] «ANSD,» [En ligne]. Available: https://www.ansd.sn/index.php?option=com_regions&view=region&id=5&Itemid=1223. [Accès le 2020].
[26] V. Sharma et S. Chandel, «Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India,» Energy, vol. 55, pp. 476-485, 2013.
[27] D. H. Daher, L. Gaillard, M. Amara, B. Lips et C. Menezo, «Evaluation expérimentale des performances d'une centrales solaires photovoltaiques de 300 kWc à Djibouti,» Science et Environnement, vol. 27, pp. 16-22, 2014.
[28] K. Padmavathi et S. A. Daniel, «Performance analysis of a 3 MWp grid connected solar photovoltaic power plant in India,» Energy for Sustainable Development, vol. 17, p. 615–625, 2013.
[29] MohdKhalid, A., Mitra, I., Warmuth, W. et V. Schacht, «Performance ratio – Crucial parameter for grid connected PV plants,» Renewable and Sustainable Energy Reviews, vol. 65, p. 1139–1158, 2016.
[30] H. A. Kazema, T. Khatibb, K. Sopianc et W. Elmenreich, «Performance and feasibility assessment of a 1.4 kW roof top grid-connected photovoltaic power system under desertic weather conditions,» Energy and Buildings, vol. 82, p. 123–129, 2014.
[31] J. Tanesab, D. Parlevliet, J. Whale et T. Urmee, «Seasonal effect of dust on the degradation of PV modules performance deployed in different climate areas,» Renew Energy, vol. 111, p. 105–115, 2007.
[32] P. Congedo, M. Malvoni, M. Mele et M. D. Giorgi, «Performance measurements of monocrystalline silicon PV modules in South-eastern Italy,» Energy Conversion and Management, vol. 68, p. 1–10, 2013.
[33] S. Sundaram et J. S. C. Babu, «Performance evaluation and validation of 5 MWp grid connected solar photovoltaic plant in South India,» Energy Conversion and Management, vol. 100, p. 429–439, 2015.
[34] M. Farhoodnea, A. Mohamed, T. Khatib et W. Elmenreich, «Performance evaluation and characterization of a 3-kWp grid-connected photovoltaic system based on tropical field experimental results :new results and comparative study,» Renewable and Sustainable Energy Reviews, vol. 42, p. 1047–1054, 2015.
[35] D. Okello, E. V. Dyk et F. Vorster, «Analysis of measured and simulated performance data of a 3.2 kWp grid-connected PV system in Port Elizabeth, South Africa,» Energy Conversion and Management, vol. 100, p. 10–15, 2015.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[36] C. B. E. Sidi, M. L. Ndiaye, M. E. Bah, A. Mbodji, A. Ndiaye et P. A. Ndiaye, «Performance analysis of the first large-scale (15 MWp) grid-connected photovoltaic plant in Mauritania,» Energy Conversion and Management, vol. 119, p. 411–421, 2016.
[37] L. C. Lima, L. A. Ferreira et F. H. B. L. Morais, «Performance analysis of a grid connected photovoltaic system in northeastern Brazil,» Energy for Sustainable Development, vol. 37, p. 79–85, 2017.
[38] A. Raghoebarsing et A. Kalpoe, «Performance and economic analysis of a 27 kW grid-connected photovoltaic system in Suriname,» IET Renewable Power Generation, vol. 11, pp. 1545-1554, 2017.