Article

Performance analysis of a 48kWp grid-connected photovoltaic plant in the Sahelian climate conditions of Nouakchott, Mauritania

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Abstract: This paper presents preliminary operational performance results of a pilot grid-connected photovoltaic (PV) system designed and installed on the rooftop of the Ministry of Petroleum, Energy and Mining headquarter in Nouakchott (latitude of 18.1°N and the longitude of 16.0°W), Mauritania. The aim is for the government to demonstrate the relevance of using solar energy and to encourage the uptake of solar PV technology for commercial and residential building applications in Mauritania.. In this study, the grid-connected PV system has a peak power of 48 kW and the performance monitoring was carried out during one year, with a system that allow to measure DC power, inverter and system conversion efficiency, energy generated by the PV arrays, solar radiation in the inclination plane of panels, ambient temperature and module temperature. During this period, the PV plant was found to supply 65,668 kWh to the grid. The final yield ranged from 3.91 to 5.09 kWh/kWp/day. The performance ratio was found to vary from 69.69% to 89.35% and the annual capacity factor was found to be 19%. Finally, performance parameters were compared with other PV plants installed in the same region of Northern Africa. The outcome of this work is deemed important in assisting accurate PV system design and decision-making.

Keywords: Grid-connected PV plant, Monitoring, Performance parameters, performance comparison, Mauritania.

Nomenclature

MPEM	Ministry of Petroleum, Energy and Mines
ANADER	National Agency for Renewable Energy Development
SOMELEC	National Electrical Company)
OMVS	The Senegal River Basin Development Organization
HFO	Heavy Fuel Oil
A_a	PV module surface (m2)

CF	Capacity factor
E_{AC}	AC energy output (kWh)
E_{DC}	DC energy output (kWh)
G_O	solar irradiance under standard test conditions (kW/m²)
I_{POA}	plane of array irradiance (W/m²)
L_C	array capture losses (kWh/kWp)
L_{cm}	miscellaneous capture losses (kWh/kWp/d)
L_{tc}	thermal capture losses (kWh/kWp/d)
L_S	system losses (kWh/kWp/d)
P	power output (kW)
P_O	PV rated power (kWp)
PR	Performance ratio (%)
PV	Photovoltaic
STC	standard test conditions
Y_a	array yield (kWh/kWp)
Y_f	final yield (kWh/kWp)
Y_r	reference yield
Y_R	reference yield (h=d)
Y_{CR}	corrected reference yield (kWh/kWp/day)
T_0	ambient temperature in standard test conditions (°C)
T_C	cell temperature (°C)
γ	maximum power temperature coefficient (%/°C)
η_{PV}	Array efficiency (%)
η_{sys}	System efficiency (%)
η_{inv}	Inverter efficiency (%)

1. Introduction

Total Mauritania installed power capacity amounted to approximately 663 MW in 2019, out of which 75 % comes from thermal power plant fired by fossil fuels, especially heavy fuel oil (HFO)[1]. In order to reduce this reliance to fossil fuels, the Government of Mauritania has formulated several policies and enabling environment with the aim to diversify the overall energy mix and to provide indigenous, affordable, reliable and sustainable energy for all, as well as energy security. By 2030, the Government of Mauritania has set a target to achieve 50 % renewable energy share in the electricity generation mix[1]. The use of renewable energy may restrict the dependency of country on imported fossil fuel (since Mauritania has not lifted yet oil and gasrecently discovered in the country). Indeed, the country is blessed with large amount of renewable energy sources. The renewable energy potential in Mauritania is strongly dominated by solar resource. The average solar radiation on a horizontal surface is estimated at 4.5-6.5 kWh/m2/day (1800-2400 kWh/m2/year) in Fig. 1 [1]. Wind resources estimates identified areas along the coast with average annual wind speeds above 7 m/s, although speeds can exceed 9 m/s in Nouadhibou[2].Traditionally used biomass has the potential to cover many energy needs if it is managed carefully in acontext of local desertification[1]. In addition, significant hydropower resourceshave begun to be tapped through the Senegal River Basin

Development Authority (OMVS), although the potential for small hydropower still needs to be assessed in the South country.

within three general climatic regions: the north, exposed to a hot and dry desert climate; the south, exposed to a more humid climate with lower solar resources; and coastal areas, exposed to lower temperatures but more humidity.

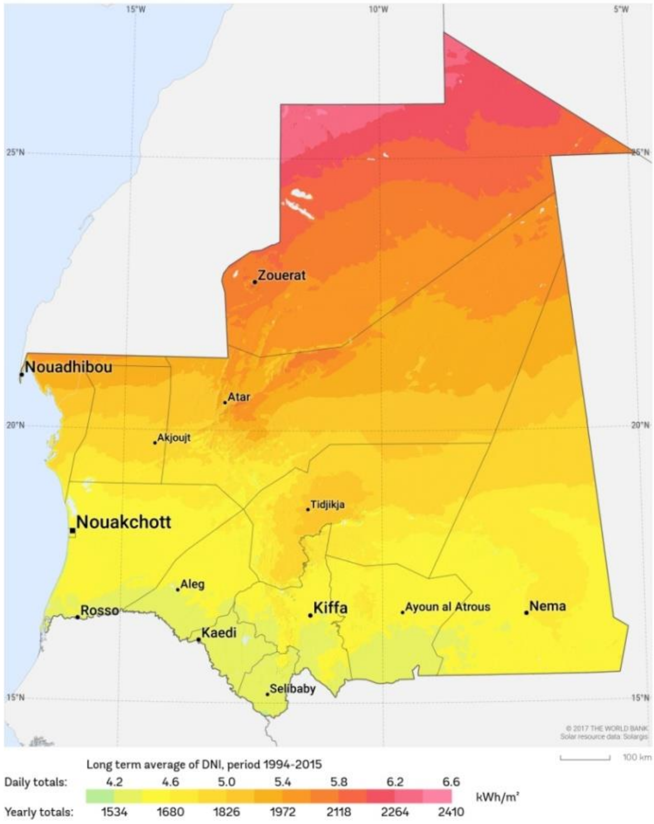

Fig. 1 Global solar irradiation in Mauritania**[1]**.

Table 1 provides an overview of estimated solar PV production potential at five sites. The projected production at these sites is substantial compared to other regions where solar energy technologies has been widely implemented, such as in Europe. The variations in production among regions are related to differences in overall irradiation as well as estimated heat losses (which can be limited through the use of appropriate technologies) and barriers such as cloud cover, wind, sand and mist.

Table 1: Potential annual electricity generation from conventional fixed PV systems

Location	**kWh generated per kW$_P$**	**Optimum tilt installation**
Nouadhibou	1780	21°
Atar	1590	20°
Kiffa	1460	16°
Rosso	1420	15°
Nouakchott	1330	16°

Table 1 also shows that the optimum tilt of solar PV panels varies between 15° to 21° respectively for the localities in the south of the country (Kiffa, Rosso and Nouakchott) and for the localities located in the north(Atar and Nouadhibou).

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In order to ascertain the real potential for PV power generation in a region, it is important to go beyond simple resource estimations based on PV installation predictive models that have been established for other climates (in particular North America or Europe). At this early stage of the development of solar energy in Mauritania, it is appropriate to make use of outdoor monitoring data retrieved from PV systems operating in the local environmental conditions [2-6]. In order to characterize the seasonal variations and related energy performances, monitoring data must at least be collected during one year [6-8] or prefer ably over a period spanning several years[7-9]. Monitoring data should include instantaneous electrical measurements (PV array and system power production) and also environmental factors (plane-of-array irradiance, ambient temperature, module temperature and wind speed), which directly affect the power output of the PV facility. As a first approach, a PV array performance depends on incident solar irradiation [10-11], modulated by the operating temperature depending of the PV modules technology[12]. This temperature dependence is more sensitive for crystalline silicon technologies, which are the most mature and currently the most widely used in the world. For a PV installation operating in East Africa, Daher et al. [9] reported that an increase of 1°C in ambient temperature resulted in a decrease in performance ratio (PR) by0.71%. Furthermore, dust accumulation reduces the power output and reduces system performance since it filters a part of incident solar irradiation. Several studies have been conducted to evaluate the performance losses due to dust accumulation on PV modules[13-14]. An average decrease of 6.2% per month of the Performance Ratio (PR)was reported by [15] in a PV system installed in the Atacama Desert.

A 48kWp grid-connected photovoltaic installation has been commissioned to assess the viability of PV under the Sahelian climatic conditions of Nouakchott, Mauritania. As the first grid-connected installation in the Islamic Republic of Mauritania, the aim for the government is to demonstrate the pertinence of solar energy and encourage its uptake for commercial and residential building applications. At the time of its construction the installation was unique in this region of Africa and also represented a tool for promotion and research for the Laboratory of the Renewable Energies on the Faculty of Sciences and Technology of Nouakchott.

The aim of this paper is to present an analysis of the data retrieved from this facility, and assess the impact of the local climate context(hot, dry, dusty, with very low rainfall, and a low latitude resulting in a shallow tilt angle of the installed panels). The PV installation was monitored during a period of one year, from January 2019 to December 2019. The PV system was evaluated based on the different performance parameters including: reference yield, PV array yield, final yield, system losses, performance ratio and capacity factor, in order to offer baseline information for energy evaluation using polycrystalline silicon PV arrays.

2. Description of the photovoltaic installation

Nouakchott is the capital of Mauritania, localized in the central southern part of the country in18.1° N latitude and 16.0° W longitude. The Nouakchott region is known as a heat-dry zone with very low rainfall and large areas of the plain. This offers an optimal atmosphere for any solar PV project. This area has been therefore identified as an ideal place to implement the first pilot rooftop grid connected PV system in Mauritania as part of efforts to promote solar photovoltaic energy. This grid connected system has been installed in 2013 on the flat roof of the Ministry of Petroleum, Energy and Mines (MPEM). It has been financed by the Mauritanian government through the National Agency for Renewable Energy Development (ANADER).The facility is illustrated in Fig. 2andFig. 3.

Fig. 2. PV roof system installation of the MPEM (building configuration and PV installation)

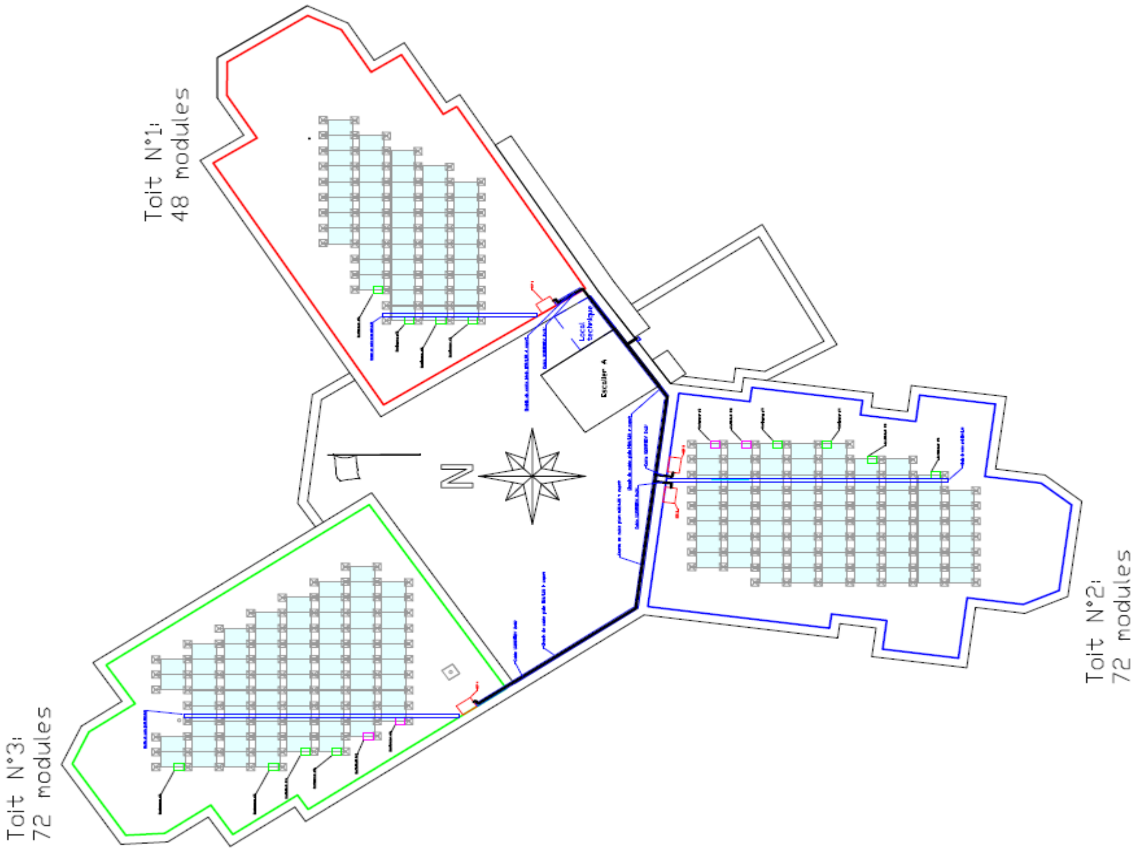

Fig. 3.PV system installation of the MPEM

Table 2: Electrical and mechanical properties of the PV modules

Model	**KGM 250M-96**
Electrical properties of the PV modules at Standard Test Conditions (STC)	

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Maximum powerPmax (Wp)	250 W
Voltage at the maximum power point V_{mp}(V)	49 V
Current at the maximum power point I_{mpp}(A)	5.1 A
Open circuit voltage V_{oc}(V)	59.8 V
Short circuit current I_{SC}(A)	5.51 A
Module temperature at NOCT	47 °C
Module efficiency	14 %
Mechanical properties of the PV modules	
Module length (mm)	155
Module width (mm)	990
Range of operating temperature	-40 °C to 80 °C

The 48kWpinstallation comprises 192 polycrystalline silicon PV modules, each with a peak power of 250 W (Model: KGM250M-96) (table 2), and covering a total area of 327 m². The panels are oriented south and inclined to a 15°(Fig. 2) to maximise annual generation for the site latitude. The panels were organised into four series-parallel arrays of 12kWp, connected at junction boxes and distributed across four 10 kW grid-tied DC-AC power conditioners Fig. 4 and Fig. 5.

Fig. 4. **Inverters (DC) input /output (AC)**

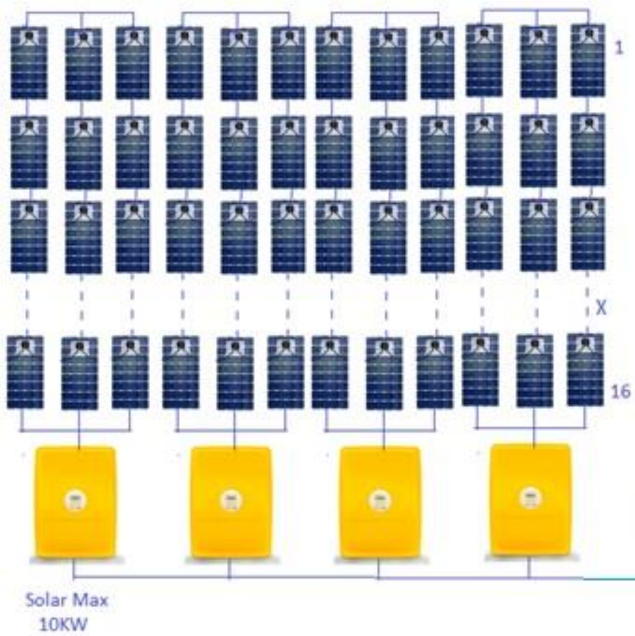

Fig. 5. Schematic block diagram of the PV system.

The installation was fully monitored for one year from using a dedicated data monitoring system with an integrated data logger (MaxVisio Comunit device). A set of meteorological sensors connected to the data logger was used to measure meteorological parameters such as solar radiation, ambient temperature, temperature of the modules and wind speed (Fig. 6). The data monitoring system was also interfaced with the 4 inverters to collect electrical parameters of the PV system. The solar radiation sensor was installed at the same tilt angle and orientation as the PV array to measure plane of array (POA) irradiance. The ambient temperature sensor and the wind-speed sensor were located close to the PV array. The modules temperature was measured by a surface mount temperature sensor placed centrally on the back sheet as shown in Fig. 7. The PV module's temperature sensor is a PT1000 (CS240DM) platinum resistive thermometer (PRT) with a measurement range of – 40°C to 135°C, with a measurement uncertainty of ±0.015 °C. To determine module temperature, a sensor was installed on one central module of each block. The module temperature is the average of the indication of all sensors. Real-time electrical data (DC current and voltage, AC current and voltage, power output from PV array and power output from each inverter were provided using the internal data acquisition system and software of the inverters. Every minute, the data logger recorded, averaged and stored all data collected, before being transferred to a specialized PC. The data acquisition system integrated all of the logged data (meteorological and electrical) and processed to provide information regarding the mean (daily, monthly) irradiance and environmental temperature as well as electrical parameters from inverters.

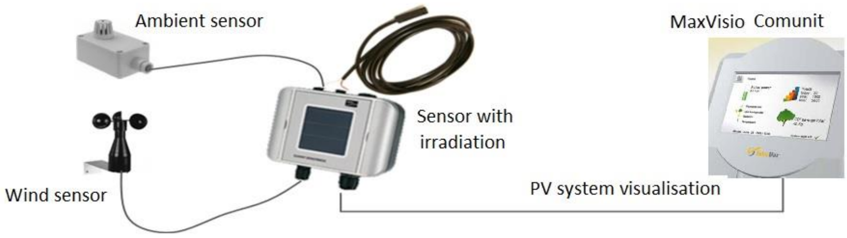

Fig. 6. Data acquisition system of the PV system.

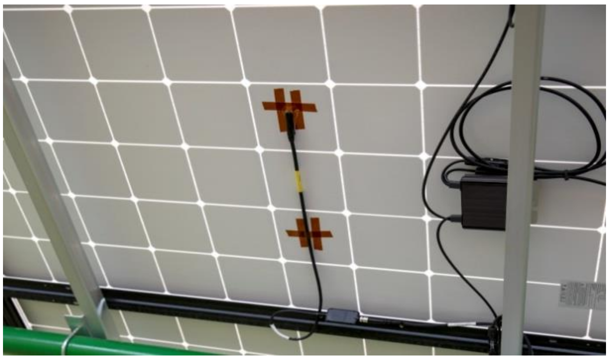

Fig. 7. Temperature sensor mounted on rear of the modules.

3. Methodology and evaluation

3.1. Performance evaluation parameters

The International Electrotechnical Commission standard (IEC-61724) specifies the set of measures proposed for the assessment of PV installations [18]. The daily performance data that are considered in this study are summarized in Table3. They include the reference yield (Yr), array yield (Ya), final yield (Yf), the performance ratio (PR), system losses (LS) and array capture losses (LC). These quantities describe the system performance as a whole in relation to energy generation, solar resources and the overall effect of PV system losses [19], [20] and [21].

Table 3.Performance data.

Performance parameters	**Definition**
Reference yield	$Y_r = I_{POA}/G_O$(kWh/kW$_P$)
Array yield	$Y_a = E_{DC}/P_O$(kWh/kW$_P$)
Final yield	$Y_f = E_{AC}/P_O$(kWh/kW$_P$)
Corrected reference yield	$Y_{CR} = Y_R(1 - \gamma(T_C - T_0))$
Performance ratio	$PR = Y_f/Y_r$(%)
System losses	$L_S = Y_a - Y_f$(kWh/kW$_P$)
Array capture losses	$L_C = Y_r - Y_a$(kWh/kW$_P$)
Miscellaneous capture losses	$L_{cm} = Y_{CR} - Y_A$(h/d)
Thermal capture losses	$L_{tc} = Y_R - Y_{CR}$(h/d)
Array efficiency	$\eta_{PV} = 100 \times E_{DC}/I_{POA} \times A_a$(%)
System efficiency	$\eta_{sys} = 100 \times E_{AC}/I_{POA} \times A_a$(%)
Inverter efficiency	$\eta_{inv} = 100 \times E_{AC}/E_{DC}$(%)
Capacity factor	$CF = E_{AC}/(P_O \times 24 \times 365) = Y_f/8760$

3.2. Meteorological data analysis

It is well known that weather-related parameters play a major role in the daily operation and performance of a PV system. The most important parameter is solar irradiation on the module plane, because as it increases, the PV system output increases too. However, the increased radiation is followed by an increase in the PV modules temperature which has important impact on their efficiency and thus on the energy yield. The variations of the ambient temperature also greatly influence the performance of the solar PV system.

In addition to the irradiation, the wind also significantly affects the performance of a PV plant as it contributes to the PV module temperature balance. Usually and depending of the ambient air temperature, a higher wind speed contributes to improve working efficiency by reducing modules temperature due to its cooling effect. The variations in weather parameters from month-to-month and year-to-year influence the performance parameters of the PV plant. Therefore, it is important to identify which performance parameters are suitable for which system evaluations based on their weather dependence.

Fig. 8 represents the daily monthly average of the global in-plane solar irradiation arriving on PV module inclined surface for a fixed angle of 15°. It can be observed that the monthly global average solar radiation is minimum in December 2019 with 4.5kWh/m2/day and maximum during June 2019 with 7.2 kWh/m2/day. According to climate characteristics conditions of Nouakchott, it can be also seen that for the period of monitoring there is two distinct different solar radiation distribution. During the hot season from March through October the total irradiance (5.5 kWh/m2/day - 7.2 kWh/m2/day) is greater than that of during the cold season from November to February (4.5 kWh/m2/day - 4.8 kWh/m2/day). Furthermore, Fig. 8 shows the monthly variation of the daily average wind speed. This later varies from a minimum of 2.1 m/s (in November) to a maximum of 3.5 m/s (in July)

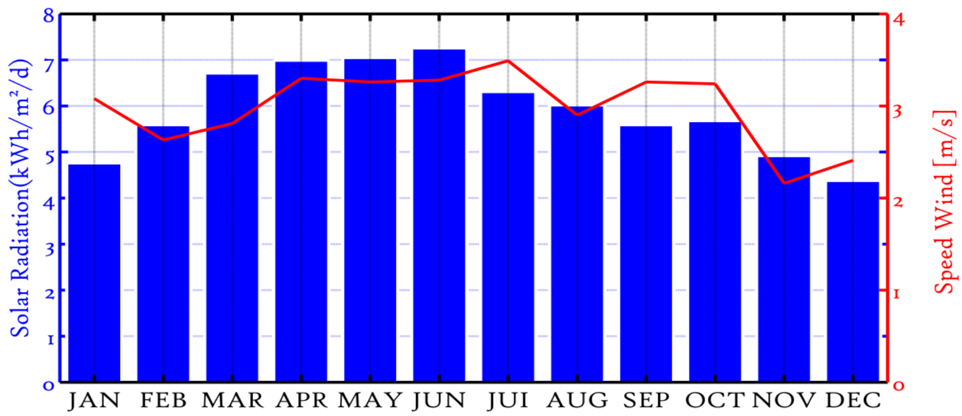

Fig.8. Monthly average daily solar irradiationandwindspeed

Fig.9 depicts the monthly variation of the daily average ambient temperature average and module temperature measured at the site area over the monitored period. The average daily ambient temperature over the year is given by 28.1°C, while the average ambient temperature per month varies between 21.4°C in January and 33.1°C in June and the average ambient temperature over the whole year was 28.13°C. The daily average module temperature ranges from 28.5 °C in January to 41.7°C in June.

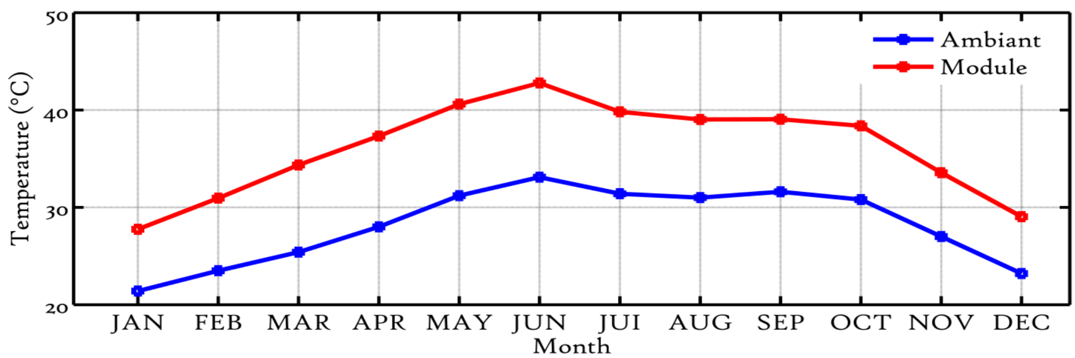

Fig.9.Daily monthly average of ambient and PV module temperatures measured in 2019

From this pattern of variation, it can be noticed that the ambient air and PV module temperatures increase as the level of solar radiation increases. It is found also that the difference between module temperature and ambient temperature follow the same trend. The maximum value of this difference is 11.2°C higher in June corresponding to the highest irradiation month while the minimum value of 5.1°C is obtained in December (lowest irradiation month). The module temperature in the field is primarily dictated by the ambient temperature and heat generated due to solar radiation incident. The ambient temperature sets the base temperature of the module and the solar irradiance sets the temperature raise of the module. The wind speed slightly influences the module temperature [10] [22].

4. Results and discussions

The evaluation of the PV facility in terms of monthly performance indicators is summarized in Table 4. The following paragraphs provide a discussion of the key observations regarding the variation in performance over the monitoring period: energy output (kWh), module efficiency (η_{PV}%), system efficiency (η_{sys}%), inverter efficiency (η_{inv}%), performance ratio (PR) and capacity factor (%).

Table 4.Energy output, ambient temperature, module efficiency, system efficiency, inverter efficiency, performance ratio and capacity factor over the monitored period.

Months	Ambient temperature (°C)	module temperatures t(°C)	Energy (kWh)	Modules efficiency (η_{PV}%)	System efficiency (η_{SYS}%)	Inverter efficiency (η_{inv}%)	Performance ratio (PR)	Capacity factor (%)
January	21.4	28.5	5014	11.54	10.73	93.05	87.78	17.41
February	23.49	30.3	4876	11.40	8.89	77.99	72.69	16.93
March	25.4	33.9	6032	11.40	9.15	80.34	74.88	20.94
April	28	36.3	5926	11.27	8.64	76.68	70.65	20.58
May	31.2	39.5	5896	11.07	8.52	77.01	69.69	20.47
June	33.1	41.7	6119	10.96	8.59	78.43	70.27	21.25
July	31.4	39.9	6054	11.04	9.78	88.59	79.95	21.02
August	31	38.9	5645	11.09	9.55	86.11	78.14	19.6
September	31.6	38.9	5176	11.01	9.43	85.6514	77.16	17.97
October	30.8	38.2	5281	11.10	9.47	85.3840	77.48	18.34
November	27	34.0	4953	11.26	10.26	91.1366	83.89	17.2
December	23.2	29.8	4696	11.52	10.92	94.87	89.35	16.31
Year	28.13	35.8	65668	11.22	9.49	84.60	77.66	19.00

4.1. Solar power generation

Fig.10 shows the monthly and integrated monthly energy generated by the photovoltaic system. The peak of energy production is reached for the month of June 2019 with 6119 kWh and the minimum energy was generated for the month of December 2019 with 4696 kWh. The observed variation in energy production was in accordance with expectations considering the monthly global irradiation as indicated in Fig.10.The total energy production accumulated for the 12 months of operation is 65,668 kWh corresponds to 1368 kWh/kWp which is in close agreement with the prediction presented in table 1.

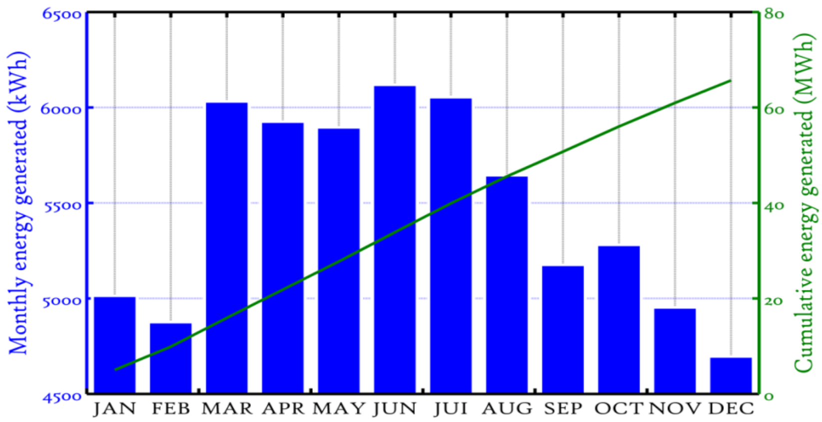

Fig.10. The total monthly electricity production in MPEM and energy accumulated

4.2. Performance evaluation

Fig. 11 shows monthly average daily reference yield (Yr), array yield (Ya) and final yield (Yf).Yr varied from 4.38 kWh/kWp/day in December to 7.25 kWh/kWp/day in June. Monthly average daily array yield ranged between 4.12 kWh/kWp/day in December-and6.5kWh/kWp/day in June. The array yield depends on availability of solar radiation, meteorological conditions of the site and the conversion efficiency of the modules.

The daily average final yield varied from a minimum of 3.91 kWh/kWp/day in December to a maximum of 5.09 kWh/kWp/day in June. This performance parameter depends on the same factors for the array yield, plus system-level losses, such as the efficiency of the inverter. Indeed, the difference between average array yield and final yield, represent the system losses mainly due to DC/AC conversion of the inverters. Those losses are reported in the following section.

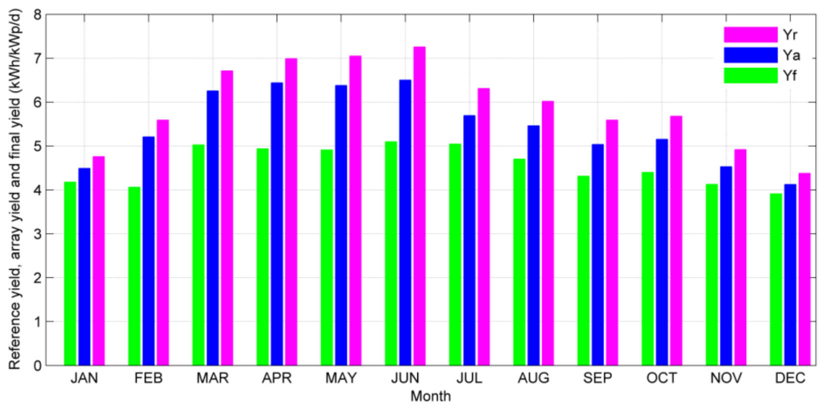

Fig.11 .Monthly average daily reference yield, array yieldand final yield.

4.3. Solar collect losses

As previously mentioned the electrical power output from a PV system depends on incident solar radiation, cell temperature, title angle of modules, and load resistance. These factors contribute to the main types of losses, include ing array collection losses, system losses, cell temperature losses, soiling and degradation losses[4].The manufacturer typically defines the specific electrical parameters of the PV module such as their open circuit voltage (VOC), short circuit current (ISC), and maximum power at standard test conditions (STC), as well as the temperature coefficient of maximum power, and nominal cell operating temperature.

The collectionlosses are a combinationof the thermal losses and miscellaneous loss factors. The monthly variation of the daily average collection losses, thermal losses, and miscellaneous collectionlosses are represented in Fig.12.The highest thermal capture losses of 0.22 kWh/kWp/day is recorded in May when the moduleoperating temperatures of 40.5°Cwere observed. The array capturelossesvary from a minimum of 0.21 kWh/kWp/day in December to a maximum of 1.5 kWh/kWp/day in April. The miscellaneous collection losses vary from a minimum of 0.1 kWh/kWp/day in January to a maximum of 0.61 kWh/kWp/day in June. These losses could be attributed to other effects than the operating temperature of the modules such as dust deposit on the PV modules or wiring losses, module performance ageing decrease and shading effects.

The thermal losses, array losses and miscellaneous losses which make up theoverall energy losses in the PV arrayare highly affected by metrological conditions such asambient temperature, wind speed in the vicinity of the solar PV plant[8,10].From the results obtained, it is concluded that the highest value of energy losses was recorded during the months of April, May and June. The lowest values of energy losses are observedinDecember and January, when the ambient temperatures wereat a minimum.

By comparison to the present study, Sidi et al. [4]reportedhigher array collect/conversion losses ranging between 1.7 kWh/kWp/day and 2.40 kWh/kWp/day. This could show that under the same climatic conditions c-Si based arrays show lower losses than a-Si arrays reported in [4].

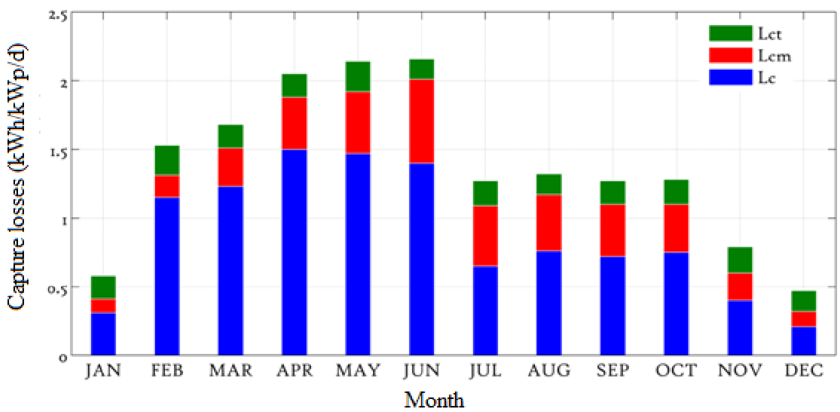

Fig. 12. Monthly average daily capture losses, thermal losses and miscellaneous capture losses

4.4. Efficiencies for: PV array (η_{PV}), system (η_{SYS}) and inverter (η_{inv})

The monthly average daily PV array (ηpv), system (ηsys) and inverter (ηinv) efficiencies over the monitoring period are shown in the Fig 12.ηPVis between 10.96% in June and 11.54% in January with a mean value of 11.22%. Since the nominal efficiency of the PV modules is 14% in the STC conditions, a comparison with the extreme values, it can be notices a difference of 2.46% with the maximum, 3.04% with the minimum and a difference of 2.78% with the average of the PV array efficiency.

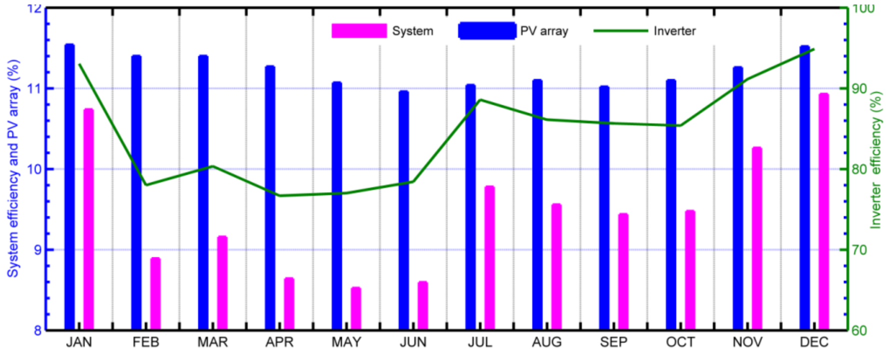

Fig.13. Monthly average daily PV array, system and inverter efficiency

The less pronounced value of the PV array efficiency that is recorded for the month of June is related to the PV module dusting rate which was higher but also the high ambient temperature compared to the other months. The variability of system efficiency is similar to PV array efficiency and ranges from8.52% in May to 10.92% in December with an average of 9.49%. The efficiency of PV inverters range from 76.68% in Aprilto94.87% in December with an average inverter efficiency of 84.60 %.

4.5. Analysis of the performance ratio (PR) and the capacity factor (CF)

The PR is evaluated on a monthly basis, revealing the highest performance to occur during December with a value of 89.35%, and the minimum is reached in May with a value of 69.69% (Fig.14). For the majority of months, an integrated performance ratio (PR) of ~70% is observed. As reported by Lee et al. [8]a PR greater than 80% should be interpreted as a system whose performance approximates the ideal performance under STC conditions, whereas a system with a PR under 70% should be suspected of failure or malfunction of the system components (panels, inverters, etc.) or environmental factors (nearby shade, excessive dusting of panels, etc).

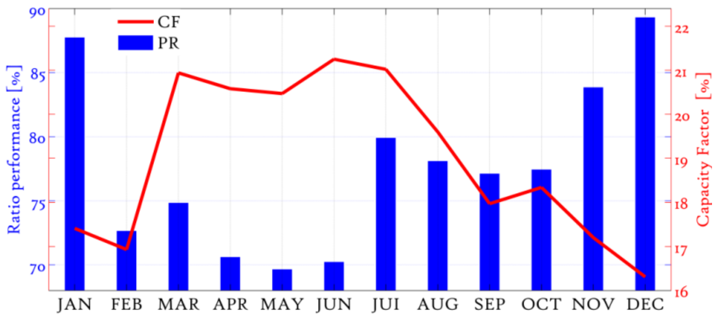

Fig. 14. Monthly average daily: final yield the PR and the FC

The capacity factor (CF) provides another measure with which to assess the overall performance of PV plants connected to the grid, and is defined as the ratio of actual AC output to nominal output for a given period. The CF indicates the duration the system would need to operate at its rated power in order to achieve the same total energy generation, expressed as a fraction of a year. Fig.13 shows the average monthly capacity factor for the year of study of the 48kWp PV solar installation. The CF varied between 21.25% in June and 16.31% for the month of December, with an average over the period of

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monitoring of19%. Hence, by the definition of CF, the energy generation is equivalent to 69.35 days of operating at full power output per year.

5. Performance comparison with other referenced literature

5.1. Global performance comparison

Performance evaluation of PV installations based on IEC 61724 standards presented in the previous section facilitates the comparison of performance from one site to another. Thus, in order to assess the performance of the power plant under investigation in Mauritania relative to other facilities, a comparative study was undertaken using the published performance of grid-connected PV systems on a global scale from all over the world: Africa [4, 9, 23-39], America [40-43], Asia [44-62], Europe [63-70] and Oceania [71]. The table 5 reviews various study on the basis of their location, mounting configuration, PV technology and performance according to IEC 61217 standards (final yield, PV module efficiency, system efficiency, performance ratio and capacity factor).

The final yield indicates the productivity of the PV system on a given location. According to the results presented in table 5, it is observed that mc-Si system installed in Safi, Morocco[36]has higher final yield with a value of 5.25 kWh/kWp. In opposition very low final yield of 1.6 kWh/kWpis observed for Jaèn in Spain[65]. This value was obtained for the PV system based on polycrystalline silicon (p-Si) technology.

Knowing that the performance ratio gives an insight between system performance and environmental conditions. Higher performance ratio is observed for Nis, Serbia[68]with a value of 93.6%.Furthermore by comparing the capacity factor reported in table 5, PV system installed in Jeddah, KSA [56] and in Kerman, Iran [57] presents higher capacity factor with a respective values of 22% and 23.2%. This shows that the grid-integration of solar PV systems should be very competitive for these countries.

In terms of photovoltaics technologies comparison, performances of different PV system based on different PV modules technologies are reported in the literature.Adaramola et al. [37] investigated the performance of five different grid-connected PV technologies (mc-Si, p-Si, a-Si, CIS, HIT) in Kumasi, Ghana. It was found that the p-Si technology is most suitable and the CIS technology is the least suitable for the humid tropical climate of Kumasi.Elsewhere, under the humid continentalclimate of Osijek, Croatia [67] it was found that mc-Si technology performs better than p-Si. The respective performance ratio and capacity factor was 74.59% and 12.69% for the mc-Si and 73.75% and 12.11% for p-Si.PV plants based on p-Si and amorphous/microcrystalline silicon tandem thin films (a-Si/µc-Si) were investigated by Ferrada et al. [42] under coastal desert climate of the Atacama Desert, Chile. It was reported from this study that the a-Si/µc-Si technology has higher final yield and lower performance ratio than p-Si. This mainly due that the thin films technology is more affected by the dust than the p-Si technology, this consequently affects its performance ratio.

It can be deduced from the above PV technology comparison that the PV technology performance is location and climate conditions dependent. Moreover, the PV mounting configuration could play an important role. The same technology (p-Si) have been tested in Sardinia by Emilio Ghiani et al. [70] but in different mounting configuration (rooftop and ground-mounted). It was reported from this study that the ground-mounted PV plant has higher performance values (see table 5) this was mainly due to the tilt angle (11° for the rooftop and 30° optimal for the ground-mounted PV system).

In the second part of this section 5, we will focus on the PV performance comparison of the Northern Africa countries.

Location	PV type (mounting)	Final yield (kWh/kWp.day)	PV module efficiency (%)	System efficiency (%)	Performance ratio (%)	Capacity factor (%)	Refs
Nouakchott, Mauritania	a-Si\µa-Si (ground)	4.27	-	-	67.96	-	**[4]**
Djibouti	p-Si (ground)	4.7	12.68	11.75	84	16.35	**[9]**
Adrar, Algeria	mc-Si (rooftop)	4.88	12.26	11.26	73.82	7.91	**[23]**
Algiers, Algeria	mc-Si (rooftop)	2.15-4.31	7-10	6,78	71	13.14	**[24]**
Batna, Algeria	mc-Si (rooftop)	3.03	9.93	8.75	57	12.63	**[25]**
Cairo, Egypt	a-Si (rooftop)	4.35	4.22	4.02	77.75	18.12	**[26]**
Cairo, Egypt	p-Si (rooftop)	3.7	-	10.38	62	15.42	**[27]**
Assa, Morocco	p-Si (ground)	4.71	-	9.97	70.14	18	**[28]**
	mc-Si (rooftop)	4.53	-	11.7	76.7	18.86	
Casablanca, Morocco	p-Si (rooftop)	4.47	-	11.4	75.6	18.64	**[29]**
	a-Si (rooftop)	4.33	-	7.21	73.1	18.05	
	mc-Si (rooftop)	4.41-5.98	15.2 %	10.79-13.81	68,5 93	18.37-24.92	
Errachidia, Morocco	p-Si (rooftop)	4.48-6.14	15.2 %	10.82-14.13	69,6-95,4	18.68-25.60	**[30]**
	a-Si (rooftop)	4.48-5.91	9.87 %	7.36-8.82	69,9-91,9	17.38-24.62	
Meknes, Morocco	mc-Si (rooftop)	4.85	-----	12.1	79.6	20.2	**[31]**
	p-Si (rooftop)	4.98	-----	12.3	81.7	20.52	
Tangier,	p-Si	1.96-6.42	12.39	12	79	14.84	**[32]**

Morocco	(rooftop)						
Tripoli, Libya	a-Si (ground)	4.63	-	7	70	19.3	**[33]**
	mc-Si	-	-	-	40.75-88.68	-	
BeniMellal	p-Si	-	-	-	41.4-91.7	-	**[34]**
	a-Si	-	-	-	39.2-80.88	-	
Ifrane, Morocco	mc-Si	4.34	-	12	77	18	
	p-Si	4.33	-	12	77	18	**[35]**
	a-Si	4.1	-	7	73	17	
	mc-Si	5.25	-	14.94	85.51	21.87	
Safi, Morocco	p-Si	5.23	-	14.91	85.37	21.81	**[36]**
	a-Si/µa-Si	4.71	-	7.6	76.66	17.90	
Kumasi, Ghana	mc-Si (rooftop)	**2.75**	**-**	**-**	67.9	11.47	**[37]**
	p-Si (rooftop)	3.1	**-**	**-**	76.3	12.9	
	a-Si (rooftop)	3.08	**-**	**-**	75.8	12.8	
	CIS (rooftop)	2.12	**-**	**-**	52.3	8.8	
	HIT (rooftop)	**3**	**-**	**-**	74.8	12.6	
Maseru, Lesotho	p-Si (ground)	3.43	10.93	9.58	67	17.2	**[38]**
Eastern Cape, South Africa	p-Si (rooftop)	4.9	**-**	11.82-12.23	84	20.42	**[39]**
Ceara, Brazil	p,Si	4.33	11.55	11.42	75.6	18.07	**[40]**
Florianopolis, Brazil	a-Si (rooftop)	3.56	3.7	3.37	50-81	-	**[41]**
Atacama Desert, Chile	mc-Si (ground)	4.36	-	-	67.3	-	**[42]**
	a-Si/µc-Si (ground)	4.63	-	-	62.9	-	
Co, USA	UMG-Si	-	-	-	84-93	-	**[43]**
Abu Dhabi, UAE	mc-Si	5.1	-	-	80	-	**[44]**
Aksaray,	p-Si	4.41	-	-	82.48	-	**[45]**

Turkey	(ground)						
Mugla, turkey	mc-Si (rooftop)	3.87	9.54	7.3	72	16.13	**[46]**
Andhra Pradesh, India	p-Si (rooftop)	-	-	-	75	21	**[47]**
Azda, Kuwait	CIGS (rooftop)	4.5	-	-	70-85	-	**[48]**
Bagdad, Iraq	HIT	4.4	13.7	13.27	75.5	18.4	**[49]**
Bangkok, Thailand	mc-Si	-	-	4.5	74	-	**[50]**
Bhubaneswar, India	p-Si	3.67	-	-	-	-	**[51]**
Daklak province, Vietnam	mc-Si (rooftop)	9.4	-	-	69	-	**[52]**
Gujarat, India	mc-Si	2.79	-	10.52	75.3	-	**[53]**
	p-Si	-	-	-	70	-	
Gurugram, India	HIT	-	-	-	83	-	**[54]**
	a-Si	-	-	-	82	-	
Haryana, India	p-Si (ground)	4.28	-	13.76	82.7	17.8	**[55]**
Jeddah, Saudi Arabia	mc-Si (rooftop)	-	-	-	78	22	**[56]**
Kerman, Iran	mc-Si	5.24	-	-	80.81	23.2	**[57]**
kovilpatti, India	mc-Si (rooftop)	4.22	-	11.65	78.48	17.99	**[58]**
Kuantan, Malaysia	mc-Si (ground)	3.67	-	11.54	-	17	**[59]**
Lucknow, India	p-Si	3.99	-	-	-	-	**[60]**

Rajkot, India	p-Si	4.49	-	-	70	-	**[61]**
Chosun University, Korea	p-Si (rooftop)	-	9.72	-	79.63	14.82	**[62]**
Dublin, Ireland	mc-Si	2.4	-	12.6	81.5	-	**[63]**
East Poland	p-Si (rooftop)	3.09	-	14.5	80	-	**[64]**
Jaén, Spain	mc-Si	2.74	-	-	-	-	**[65]**
	p-Si	1.6	-	-	-	-	
Ås,Norway	p-Si	2.55	-	11.6	83	10.53	**[66]**
	mc-Si (rooftop)	-	11.46	-	74.59	12.69	**[67]**
Osijek, Croatia	p-Si (rooftop)	-	10.42	-	73.75	12.11	
Nis, Serbia	-	-	-	11.3	93.6	12.88	**[68]**
	mc-Si (rooftop)	3.83	14.2	11.5-18	89.1	-	
Trieste, Italy	HIT (rooftop)	3.49	14.3	12.8-16	82.7	-	**[69]**
	p-Si	4.68	-	-	87.3	19.5	
Sardinia, Italy	(ground)						**[70]**
	p-Si (rooftop)	4.05	-	-	83.2	16.88	
Wellington, New Zeeland	mc-Si	2.99	-	11.96	78	-	**[71]**
Nouakchott, Mauritania	**p-Si (rooftop)**	**4.56**	**11.22**	**9.49**	**77.66**	**19**	**Present study**

5.2. Northern Africa PV power plant performance comparison

An overview of PV power plants performance at different places in the world has been reported by Srivastava et al. [72]. Africa is not well represented in the aforementioned study, only three references are cited. However, Africa and more specially its northern

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part has witnessed a widespread deployment of grid-connected solar photovoltaic systems in the last decade. Several studies [23-36]have focused on the performance analysis of PV solar plants in Northern Africa. Moreover, Bennouna et al. [73] reported performances of three silicon-based PV module technologies in 20 sites of Morocco. But to date, no study has focused on a comparison of the PV power plants performances in northern Africa. In this sense, the present work aims to perform a thorough performance comparison concerning this region. Table 5presents the most relevant performance parameters for different PV grid-connected systems in Northern Africa reported in the literature compared to the present study.

It can be observed in this table that:

The mono-crystalline silicone (mc-Si) technology performs better in Adrar[23] (Saharan Southern Algeria) than in Algier[24] and Batna [25] (Northern, Algeria). This is correlated to the higher average daily in plane of irradiance in Adrar of 6.22 kWh/m2/day, compared to the irradiation rate of 4.83 kWh/m2/day in Algiers and 5.21 kWh/m2/day in Batna.

In the hot desert climate of Cairo, it can be observed that the grid-connected PV system using a-Si [26] performs better than p-Si [27] based PV system with respectively performance ratio 77.75 % and 62%. According that the PR takes into account the overall losses of a PV system, this lower performance in the case of [27] can be attributed to the high losses in this system.

The mc-Si performs better than p-Si and a-Si based technology under the Mediterranean climate of Casablanca [29],the respective system efficiencies are(11.7% / 11.4% / 7.21 %) and performance ratios are (76.7% / 75.6% / 73.1 %).

In the Mediterranean semi-continental climate of Meknes, p-Si has a slightly higher performance compared to the mc-Si installation [31].

Other studies on grid-connected performances parameters have been reported in this study from Assa[28],Errachadia[30] and Tangier [32] in Morocco and Tripoli [33] in Libya.

The reported performance parameters of a 15 MWp PV power plant [4]based on amorphous silicon (a-Si) and micro-amorphous silicon (μa-Si) technologies show a final yield of 4.27 kWh/kWp and a performance ratio of 67.96 %,somewhat lower than the 4.56 kWh/kWp final yield and 77.66% performance ratio of the present study. a-Si cells are affected by the Staebler-Wronski effect, which causes rated power output to decline rapidly in the first period of around 100–1000 hours of outdoor exposure until a degraded steady state is reached [4].This shows that the p-Si technology performs better than a-Si under the Sahelian climate of Nouakchott, Mauritania. Depending on the geographical location and climate conditions the performance parameters reported in the present study have been found either higher or lower than the performances of other grid-connected PV systems. Overall, plants operating in Northern Africa show high performances due to favorable solar radiation conditions.

Owing to the similar definition of the two quantities, plotting CF against Yf should reveal a trivial correlation for datasets comprising a complete year of operation. The scatter plot presented in figure 15 reveals those installations for which this was not the case. In particular the results for the Adrar facility indicate a spuriously low CF despite a daily Yf of 4.88 kWh/kWp/d. The reported performance of this installation is therefore assumed to not be representative of a complete year. Similarly, the reported lower performance of Tangiers and Algiers are interpreted as periods of unfavourable weather conditions,

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whereas the upper values for the same sites correspond to the most productive period of the year. The latter follow the trend of the other sites, and hence are assumed to be more representative of the performance during the year. However for a comparative analysis of climate effects it is more appropriate again to exclude them.

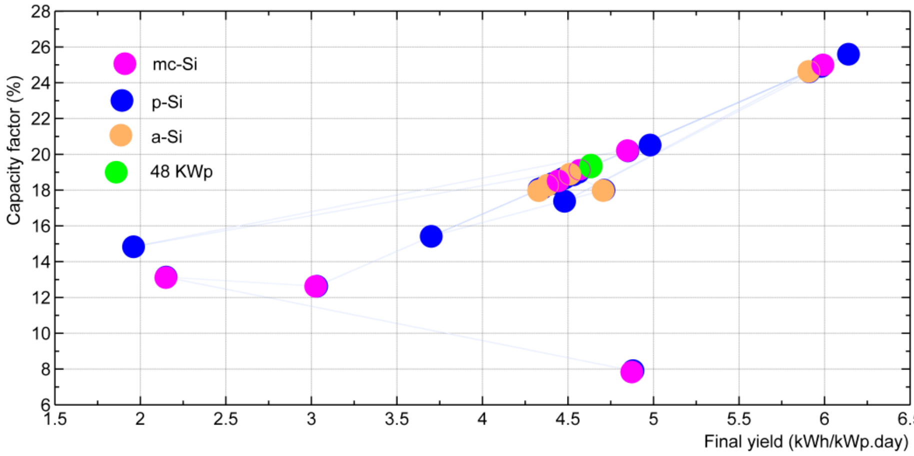

Fig.15.Capacity factor versus final yield

Fig.16 shows a scatter plot of PR versus Yf, which provides some indications of the differences between sites arising from climate and technical factors. Focusing on the central group of points, serves to select installations operating under similar environmental conditions. In this group it can be seen that the a-Si PV power plants tend to exhibit a better PR than mc-Si at the same sites, suggesting smaller system losses due to temperature for the case of a-Si.

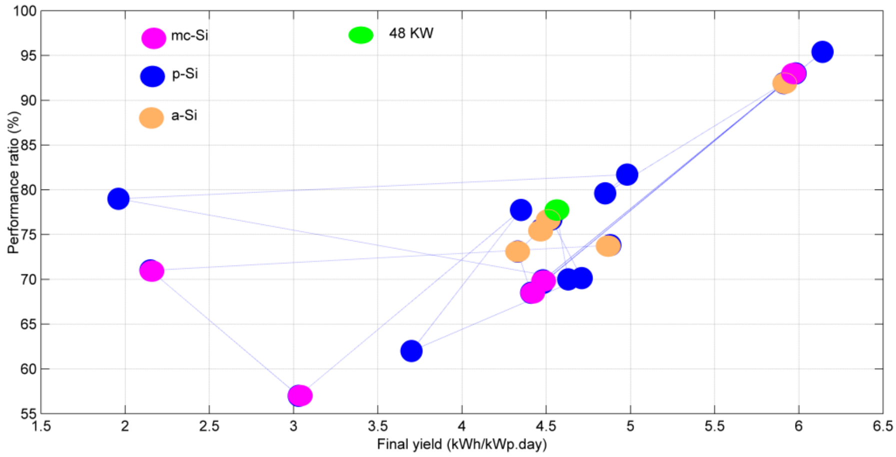

Fig.16.Performance ratio versus final yield.

6. Concluding remarks and further works

The performance analysis of the grid-connected PV system installed in 2013 on the rooftop of the Ministry of Petroleum, Energy and Mines (MPEM) in Mauritania, has been presented and its performance have been evaluated. The monitoring results are examined to analyse the behaviour of the PV plant in the sahelian climatic conditions of Nouakchott, Mauritania, as a conclusion the following results are obtained:

- The total annual electricity delivered to the grid was found to be 65 668 kWh.

- The annual average PV module array, system and inverter efficiencies were: 11.22%, 9.49% and 84.6% respectively.

- The annual average final yield was found 4.56 kWh/ kWp/d. By comparison to other systems installed in different locations world-wide it was found that the PV system has higher average daily final yield.

- The average annual performance ratio and capacity factor were found 77.66% and 19%, respectively.

- A performance comparison with several PV grid-connected power plants installed in Northern Africa was conducted and it was concluded that depending on the geographical location and climate conditions the performance parameters reported in the present study are either higher or lower than the performances of other grid-connected PV systems.

- It can be concluded that Mauritania is one of the truly favourable locations in Africa for the use of solar PV systems due to the high level of solar radiation. Although the main source of electricity production in Mauritania is oil, but solar PV systems can play a vital role in the future in reshaping the power supply system towards a more sustainable, clean, and reliable energy system.

In perspective, this problem has been we tackled whiletakingintoaccount the specifications of the Mauritanianclimate and in general the climate of arid zones with the launch of a projectentitled: "Development of a R & D platform for instrumentation and monitoring of a photovoltaicsolar system (PV) composed of several technologies of PV modules"

This projecthad the financing of the AUF thisyear; itacts to develop a platform of research and development for the follow-up of the performances of differentphotovoltaicsolar technologies in an arid zone for the optimization of the instantaneous production and the preservation performance over time. This objective canbeachieved by an accurateevaluation of photovoltaic technologies performance without underestimating the impact of climatic and environmentalfactors (temperature, solar irradiation, dust). It follows an analysis of performance degradation over time and the development of a decision support tool.

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