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Performance Analysis of Amorphous Photovoltaic Module Technology in Laâyoune -Morocco

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Abstract: *The main objective of this work is to study the performance of photovoltaic module based on silicon amorphous technology (a-si) installed on the roof of a building 10 m high of ESTL (Morocco). The system was monitored between December 2017 and November 2018 and all the electricity produced was injected into the building's low voltage power supply. The elements of performance evaluated monthly and annually include: energy output, system efficiency, reference yield, final yield, performance ratio and annual capacity factor. For a-Si, the investigation of the annual : Productivity EAC, System efficiency* η_{sys}*, and performance ratio (PR) are found as 2868,33kWh, 8,67%, and 79,28% respectively. The average annual daily final yield and capacity factor were 1889,8h and 16.3% respectively.*

Keywords: *Capacity factor, Energy yield, Final yield, Reference yield, Performance ratio*

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I. Introduction

The conversion of solar radiation into electrical energy, called photovoltaic effect, was discovered by Antoine Becquerel in 1839, after a century physicist have developed this discovery to improve energy production. The term "photovoltaic", was formed from the words "photo", a Greek word meaning light, and "Volta", the name of the Italian physician Alessandro Volta, who invented the electrochemical cell in 1800 [1], [2]. Photovoltaic systems do not contain any moving parts. They are reliable, require little maintenance, are silent and produce no emission of pollutants. The development of photovoltaic electricity production is very much at the domestic level, particularly in countries where environmental problems are taken seriously (Japan, Germany, Switzerland, etc.) and in developing countries.

In Morocco renewable energies are free and available sources of energy in most regions of country that not only offer an effective solution to reduce CO2 emissions, but can also satisfy part of the electricity consumption while reducing imports of energy oil [3]. Indeed, Morocco has significant potential for renewable energies and energy savings, including high solar radiation (5kWh/m²/day), a large wind resource (6000 MW potential) and significant potential for systems mini-hydraulic (more than 200 sites) [4]. The launch of Morocco in the way of major projects "Renewable Energies", especially in the field of solar energy, wind and hydroelectric, will allow these local resources to contribute significantly to the economic and social development of the country.

This work is part of the "PROPRE.MA" project, proposed by the Faculty of Science Semlalia Marrakech and financed by IRESEN. The primary goal of "PROPRE.MA" consists to address grid-connected PV yield maps for the whole country with ground calibration on 21 identical plants installed in partner institutional buildings located in 22 different Moroccan cities. Each plant consists of three grid-connected PV systems using monocrystalline, polycrystalline and amorphous silicon technologies. A monitoring system has been constructed to evaluate the produced energy by PV systems and investigate the effect of meteorological conditions on their performance [5].

The main purpose of this paper is to evaluate the performance of 1,55kWp system constituted of amorphous silicon panels (a-Si) technologies for one year period under Laâyoune climate conditions. The collected data along one year and PVGIS solar radiation estimate tool have been used for this comparison, in order to investigate the performance of amorphous silicon panels (a-Si).

II. Description of location

The 1,55KWp grid-connected PV systems are installed on the roof of High School of Technology-Laâyoune (ESTL)with a latitude of 27°07'50.4" North and a longitude 13°08'18.1"West. Laâyoune is the most important city of the Moroccan Sahara, it belongs to the region Laayoune-Sakia El Hamra. It is located at the edge of the Atlantic 500 km south of the city Agadir. For Laâyoune's climate is almost desert like without excessive heat due to the low amount of rainfall. Temperatures rarely exceed 28°C due to the cool sea winds.

III. Installation PV

The grid-connected PV system includes 10 amorphous silicon thin-film panels (a-Si), each one with 155Wp. PV panel power were placed on the roof of High School of Technology- Laâyoune. The PV modules are mounted facing south with a near to latitude tilt angle (30°), supposed close to the optimal value to provide a maximum annual yield. The appearance of PV systems on the roof surface is given in Figure 1. The module was connected to a inverter with conducting wire. Electrical energy produced by PV module and converted into AC currency (230V and 50Hz) via an inverter was transferred to power plant connected to ESTL building. The inverters used in the system are shown in Figure 2. the system has been installed since December 2017. It collects data with a recording interval of 5 minutes. for meteorological data, in general, the site is characterized by high solar irradiation and large ambient temperature values.

Figure 1 : ESTL PV systems Amorphous

Figure 2: Connected inverters of installation

1. PV panels

The PV system was installed on the roof of block pedagogic building. It consisted of ten modules covering a total area of 14m^2 with an installed capacity of 1.55kWp within the range of typical domestic installations. Our photovoltaic installation module amorphous contains 10 Next Power modules of 155watts each one is facing equator and tilted by 30°. The characteristics of PV modules specifications are presented in Table 1.

Trade Mark	*NEXPOWER*
Model	*NT-155AF*
Solar Cell	*THIN FILM, Amorphous Si*
Maximum Power At STC (Pm)	*155W*
Maximum Power Point Voltage (Vmp)	*65,9V*
Maximum Power Current (Imp)	*2.43A*
Open Circuit Voltage (Voc)	*85.5V*
Short Circuit Current (Isc)	*2.56A*
Length	*1,4m*
Width	*1m*
Weight	*19,5Kg*

Table 1 : PV modules electrical characteristics.

2. Inverter Sunny boy 2000HF-30

The architecture of our installation is represented in figure 3. In this architecture an inverter is placed at the end of chain which aim to increase the number of DC/AC converter which leads to the possibility of extracting the maximum power [6]. It is possible to follow monthly and total production information by software adapted to the inverters, whose size is $348 \times 580 \times 145\ \mathrm{mm}^3$ and it weighs about 17 kg. In table 2 we shows the specifications of Sunny Boy inverter 2000HF-30.

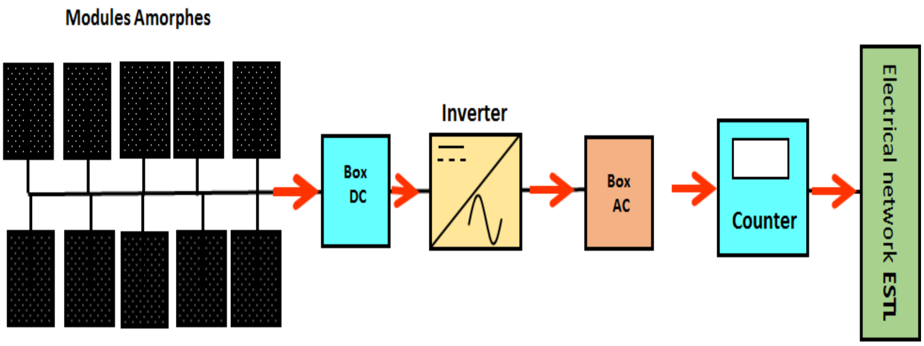

Figure 3 : Block diagram of the entire photovoltaic system

Inverter Mark	***Sunny Boy 2000HF-30***				
Input DC	*Max DC Power*	*2100W*	*Output AC*	*Rated AC Power at 230V, 50Hz*	*2000W*
	Max DC input voltage	*700V*		*Max AC apparent Power*	*2000VA*
	MPP voltage range	*175-560V*		*Nominal AC voltage*	*220V/230V/240V*
	Rated input voltage	*530V*		*Max output current*	*11,4A*
	Min DC input Voltage	*175V*		*Power factor at rated power*	*1*
	Start input voltage	*220V*		*Feed-in phase*	*1*
	Max input current	*12A*		*Connection phases*	*1*
	Max input current per string	*12A*			
	Number of MPP tracker	*1*			
	String per MPP tracker	*2*			
Efficiency	*Maximum efficiency* η_{max}				*96,3%*
	European weighted efficiency η_{EU}				*95%*
Dimensions (W×H×D)					*348×580×145mm*^{3}
Weight					17Kg
Operating temperature range					-25 to +60°C
Maximum permissible value for relative humidity					100%
Air pressure range					79,5KPa to 106KPa

Table 2 : Sunny Boy 2000 HF inverter specifications.

IV. Performance analysis

The performance is directly related to solar irradiance, ambient temperature and other atmospheric conditions factors such as soiling [7] [8]. Degradation and progressive failure mechanisms also influence the long-term performance [9] [10] [11]. The direct conversion of sunlight into electricity using PV cells is dependent primarily on the quantity (intensity levels) and quality (spectral distribution) of light. In this context, AC power, DC power, solar irradiance and surface area are used to calculate the performance of modules

3. Energy produced by the PV panels

The amorphous photovoltaic generator installed at ESTL peak power 1,55kW. We will compare its photovoltaic productivity, instantaneous, daily and monthly. The integration of the instantaneous values of the maximum power into the measurement interval generates the energy E_{AC}. The Monthly generated energy is calculated with equation (01).

$$E_{Ac,m} = \int_0^{t_s} P_{AC} dt \qquad (01)$$

t_s is the integration period and dt is the duration and P_{AC} the power of AC electricity output [12]. The instantaneous energy output was obtained by measuring the energy generated by the PV system after the DC/AC conversion on 5 min intervals, like it was done by [13].

4. System efficiency

The instantaneous system efficiency ($\eta_{Syst,inst}$) is an important parameter. The power conversion efficiency for one square meter surface area depends on size of PV modules, AC power (P_{AC}) and solar irradiance G_{opt} as given in equation (02) [14].

$$\eta_{Syst,inst} = \frac{P_{AC,inst}}{S \times G_{opt}} (\%) \qquad (02)$$

$P_{AC,inst}$ is AC power obtained from inverters, G_{opt} is instantaneous solar irradiance (W/m^2) and S is the area of PV amorphous array(m^2). We can also calculate System efficiency as the energy produced by the system to amount of radiation reflecting onto PV surface ratio for monthly period by the equation (03) [14].

$$\eta_{Syst,m} = \frac{E_{AC,m}}{S \times G_{opt,m}} (\%) \qquad (03)$$

$E_{AC,m}$ represent monthly AC energy amount transferred to power plant by the system (kWh) and $G_{opt,m}$ monthly radiation reflecting onto unit area of panel surface (kWh/m²).

5. Reference yield

The reference yield (Y_R) is the time which PV module operates under STC. It represents the ratio of the total in-plane solar insolation G_{opt} (Kwh/m²) divided by the array reference irradiance (G_{STC}=1kW/m²). It is therefore calculated by equation (04) [15].

$$Y_R = \frac{G_{opt}}{G_{STC}} \qquad (04)$$

6. Final yield

The PV system final energy yield Y_f is defined as the total energy produced by a PV system at the AC side (E_{AC}) during a period further (annual, monthly or daily) divided by P_{STC} rated power of the installed PV array at standard test conditions (STC) of 1kW/m² solar irradiance and 25 °C cell temperature. The final yield, Y_f is given by equation (05) [16].

$$Y_f = \frac{E_{AC}}{P_{STC}} \qquad (05)$$

7. Performance ratio

Another common indicator, that normalizes the energy fed to grid with respect to the received irradiance, is the PR which is defined as the ratio of the final yield to the reference yield. It indicates the overall effect of the losses on the nominal power of the PV system due to the temperature of the module, the incomplete use radiation and inefficiencies or system failures . PR is calculated using equation (6)[13] et [17].

$$PR_j = \frac{Y_f}{Y_R} (\%) \qquad (06)$$

V. Results and discussions

In order to analyze and evaluate the energy related performance of PV systems technology (a-Si), some important parameters are to be computed using data collected during its operation in a given location. These parameters include: total energy generated by the PV system E_{AC}, monthly and annually system efficiency $\eta_{sys,m}$ $\eta_{sys,y}$ reference yield Y_R, final yield Y_F, performance ratio PR and capacity factor CF which are described by IEC 61724:1998 and the international energy agency task II database on photovoltaic power system [18] and an environmental performance.

PVGIS is one of the several simulation tools which is developed to help engineers and researchers in the design, the performance assessment and the feasibility of solar PV power plants in worldwide. This system allows us to determine the real performance of our installation because it makes it possible to calculate long term average values of the irradiation [19] [20]. Figure 4 show the monthly tilted solar irradiation in Laayoune generated from the PVGIS.

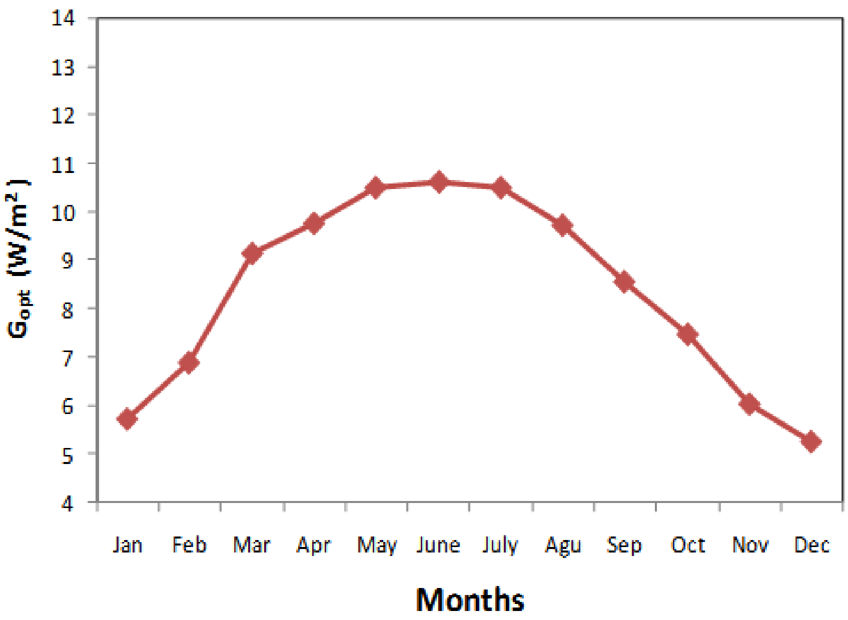

Figure 4: Daily average radiation amount according to month

8. Production analysis

The instantaneous energy output was obtained by measuring the energy generated by the PV Amorphous system after the DC/AC inverter on 5 min intervals. Figure 5 shows the monthly total energy generated by the PV system over the monitored period which varied between 204 kWh in October and 285 kWh in March. Annual total energy generated by the PV system was 2868,33 kWh.

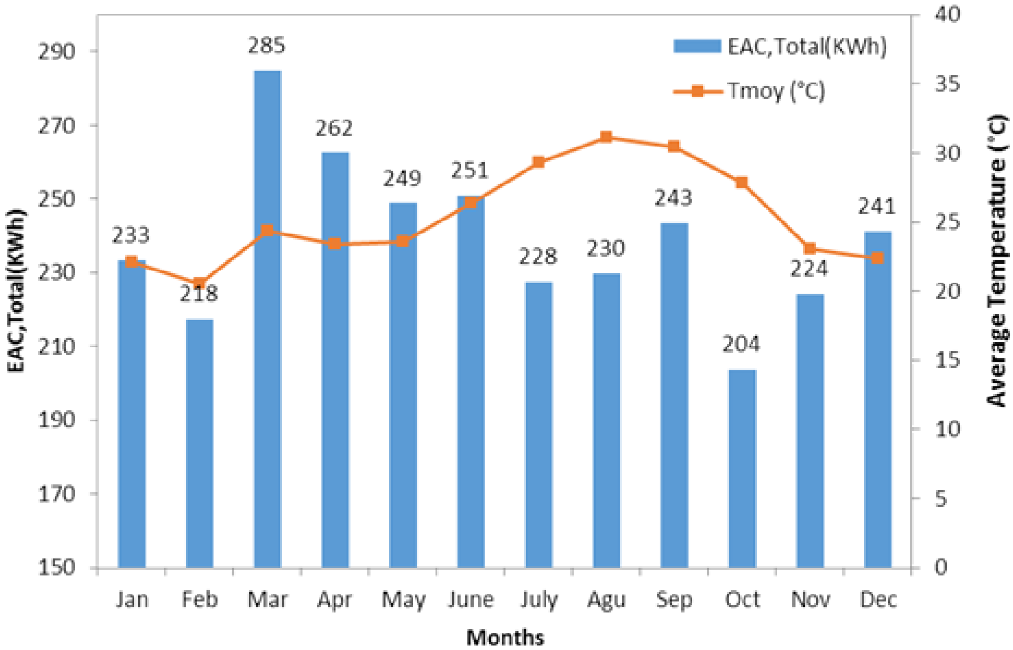

Figure 5: Monthly total energy generated between Dec. 2017 and Nov. 2018.

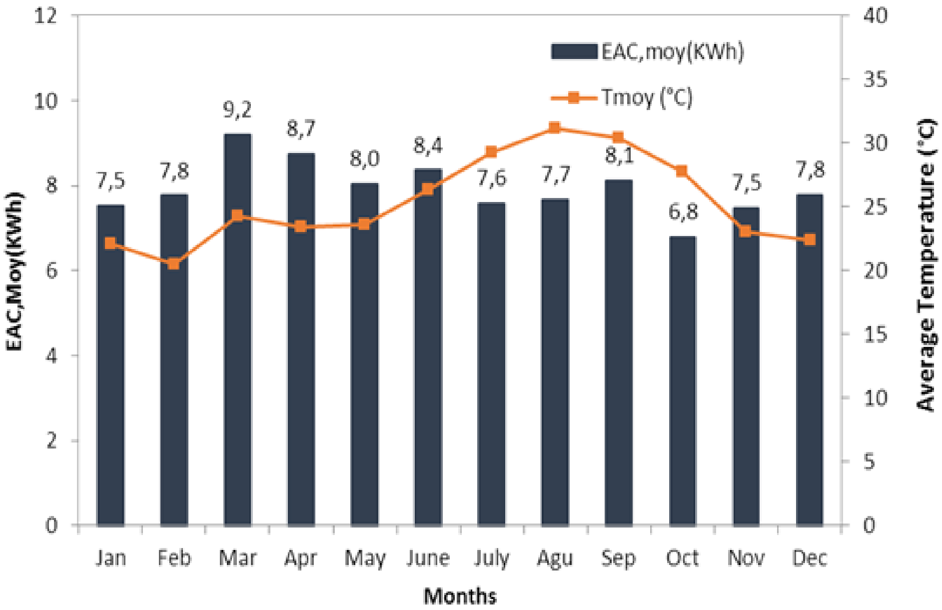

Figure 6: Monthly average of the daily AC electricity generated between Dec. 2017 and Nov. 2018.

9. System efficiency

Figure 7 shows the monthly energy generated and and system efficiency over the monitored period of PV module. The system efficiency varied between 7,3% in October and 9,9% in December. The annual average system efficiency $\eta_{sys,y}$ was 8,67%.

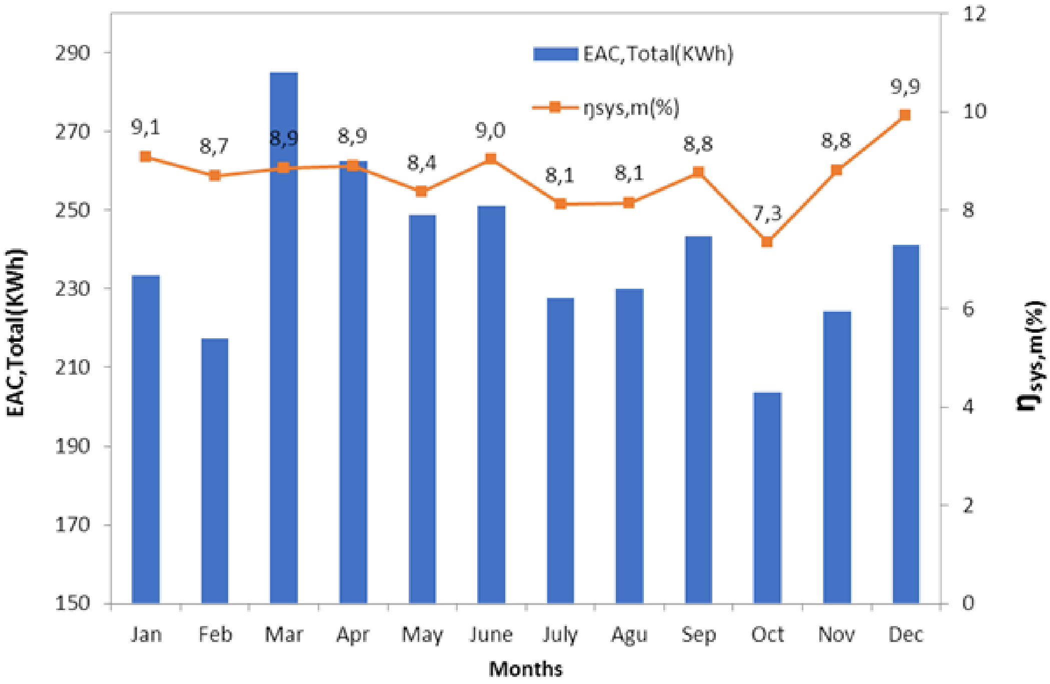

Figure 7: Monthly energy efficiency between Dec. 2017 and Nov. 2018.

10. Reference and Final yields

Figure 8 shows the monthly average daily final yield and reference yield. The final yield varied between 4,41h/day in November and 5,97h/day in March. The maximum daily final yield was recorded un spring months, because the temperature being at its best related to the module temperature. For the average annual final and reference yield were 1889,8h and 2387,4h respectively.

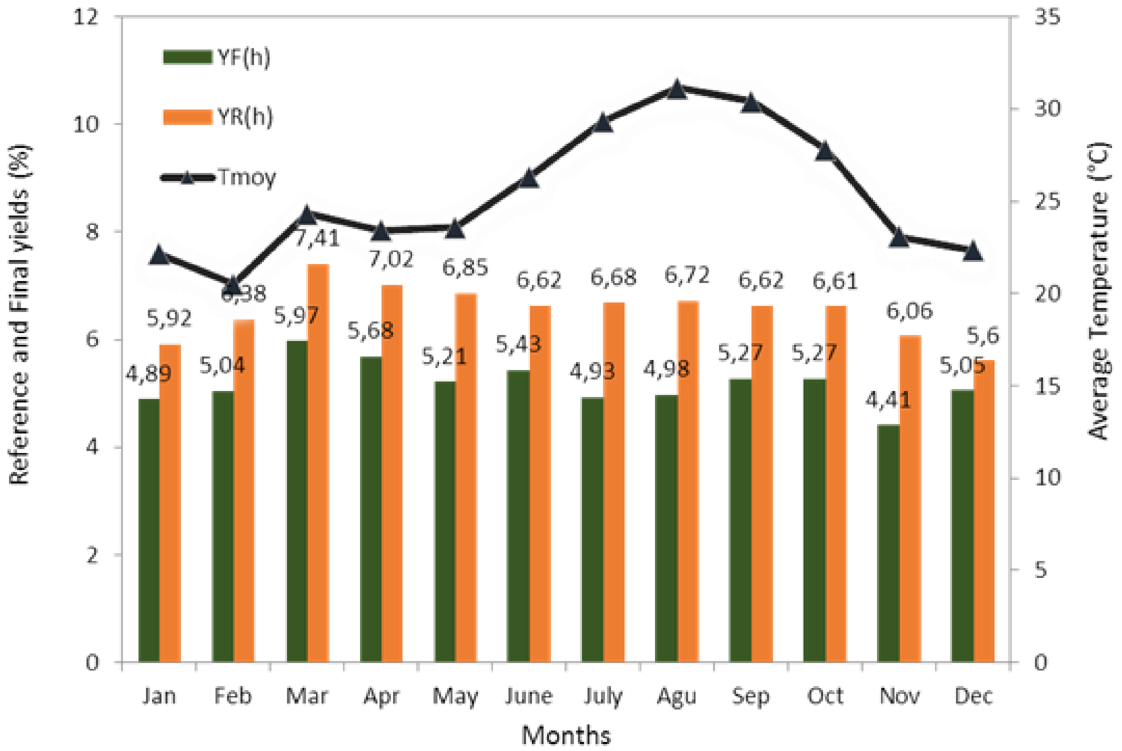

Figure 8: Monthly average daily Final and Reference yields of PV Amorphous system

11. Performance ratio

Performance ratio is an important parameter to evaluate the performance of a relative efficiency of a PV system [21]. PR of Amourphe (a-Si) PV panel's values change in range of 72,75% and 90.21%. PR of Amourphe (a-Si) panels have better results in cold time December and January. For our installation and under climate conditions of site the yearly average value of PR of Amourphe (a-Si) was 79,28%.

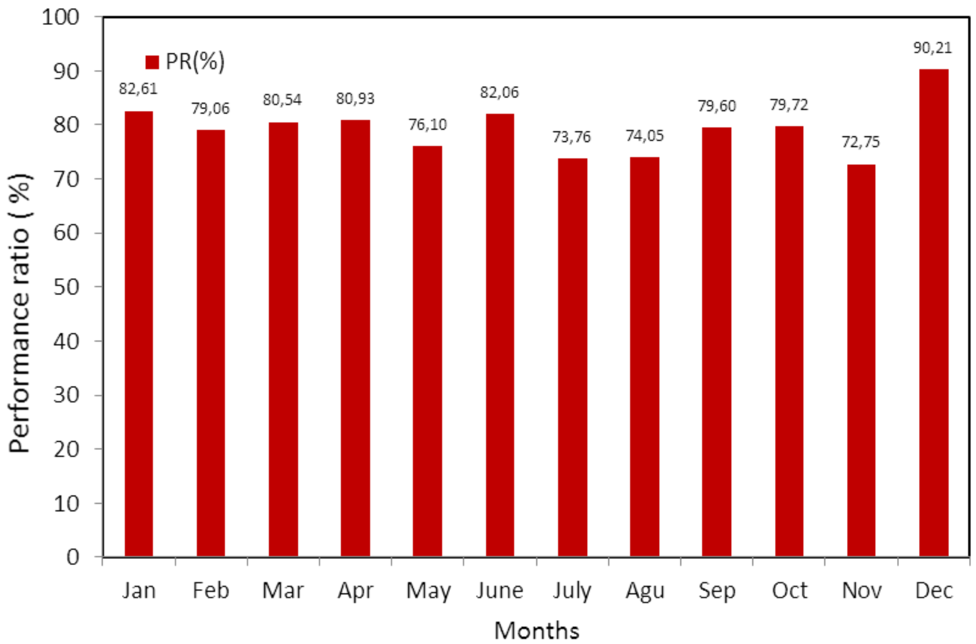

Figure 9 : Performance ratios of PV Amorphous system

VI. Conclusion

The present paper investigates the performance analysis of 1.55kWp grid-connected PV systems includes 10 amorphous silicon thin-film panels (a-Si) installed on the roof of block pedagogic building at the High School of Technology- Laâyoune (Morocco). Meteorological data of the site were derived from PVGIS database and by using real data of production for one year operation. Monthly and annual performance indicators were calculated. The following conclusions can be drawn for the period of investigation from November 2017 to December 2018:

- Total electrical energy generated was 2868,33kWh
- Average annual system efficiency of the PV system was 8,67%
- Average annual performance ratio of the installation was 79,28%.
- Average annual daily final yields was 1889,8h.
- The annual capacity factor of this installation was 16,37%

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