A One Year Performance Evaluation of an Amorphous Grid Connected PV System Facade Mounted at Bou-Ismail, Algeria

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Abstract: This paper treats one year monitoring of a 2.4 kWp amorphous grid connected PV system facade mounted at UDES' site located at BouIsmaïl (latitude 36.66, longitude 2.71), Algeria, in a coastal zone of Mediterranean Sea. The operational and meteorological data are collected between January 2016 and November 2016. During the monitoring period, the PV system has generated about 850kWh with a daily average energy of 3.25 kWh/d. The daily average of the final yield, the performance ratio and the capacity factor are 1.35h/d, 0.57 and 6.29% respectively. The capture and system losses are 0.87h/d and 0.15h/d respectively.

1 INTRODUCTION

To satisfy the growing demand of electricity and reduce the greenhouse gas emissions that lead to global warming, Renewable Energies seems to be one of the relevant solutions to be adopted.
As the residential sector is the largest consumer of energy, about 40% of the total energy consumed in the world (A. Khuram Pervez et al.,2017), and as the most of the buildings and houses are located in the cities it appears that the Building Integrated Photovoltaic (BIPV) and Building Added Photovoltaic (BAPV) may represent a powerful solution to meet the ever increasing demand by zero energy and zero emissions buildings.
As the available areas to install the PV plant on the roofs in the cities are very limited, the facades could be used to increase at the same time the size of the PV array and the production of electricity.
In order to explore the potential of the BAPV system a 12.5 kWp photovoltaic pilot plant composed of six photovoltaic arrays of different technologies which are connected to the grid and integrated on the conference room of the UDES Unit is investigated. The crystalline PV modules are installed on the roof while the thin film PV modules are mounted on the facades. This choice is dictated by the fact that the last modules are cheaper than the crystalline, and less sensitive to temperature even if there are installed on the walls. However, their efficiency is lower than that of crystalline module but more stable in diffuse solar radiations.
This paper treats the case of one of the six subsystems composing the on grid PV platform namely the amorphous silicon (a-Si) photovoltaic subsystem. At first, a description of the a-Si PV system is given, then the experimental results obtained during the test period ranging from January 2016 to December 2016 are presented.

Figure 1: View of the 2.4 kWp amorphous Silicon facade mounted PV plant

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Finally, the evaluation and analysis of the performance of the a-Si PV plant is conducted for the monitoring period.

2 SYSTEMS DESCRIPTION

2.1 PV System Description

The 12.5 kWp Multi technology solar PV plant grid connected is located at UDES BouIsmaïl (latitude of 36°38, longitude of 2°41), and altitude of 13 m above sea level, Algeria. It consists of six independent sub system, each of them using one type of solar cells technology (mono Si, poly Si, or thin films). The aim of the study is to follow up the 2.4kWp amorphous Silicon (a-Si) thin film PV plant mounted on the facade of the conference room, Fig1. Its electrical and technical properties are summarized in Table 1. This PV plant is composed by 20 a-Si Schott modules configured in two strings, each string consists of 10 modules in serial. The overall surface area of PV plant system is 30m².The a-Si PV generator is connected to the grid through a SOLARMAX S2000inverter as shown in Fig 2.

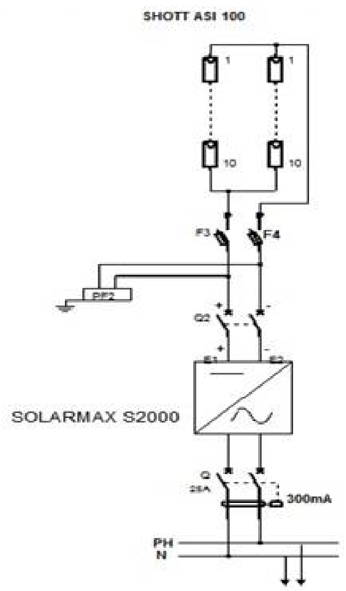

Figure 2: Diagram of the 2.4kWp a-Sigrid connected

PV plant.

2.2 Monitoring System Description

The PV system is fully monitored with Solarlog 300data logger. It is linked to the inverter through RS485 cable. The recorded data provided by the inverter are: the DC current and voltage, the AC current and voltage and the DC and AC power. The radiometric and metrological data are measured and collected by a meteorological station installed at UDES site, BouIsmaïl. The irradiance on vertical plane used in this study is measured by a-Si reference cell located in the same plane as the a-Si PV modules. The data are recorded and saved at a pace of 5mn. The monitoring system was designed to meet the standard IEC 61724(Chikh M et al.,2015).

3 PERFORMANCE PARAMETERS

The evaluation of the PV system performance is done according to the performance parameters defined in the IEC 61724 standard (IEC 61724,1998), and given in the following:

Table 1: SCHOTT a-Si PVmodule and SOLARMAXS2000 inverter characteristics.

Module Specifications	
Manufacturer	SCHOTT
model	ASI-100
Cell type	a-Si/a-Si tandem
Nominal power P_{max}[W]	100
Open circuit voltage V_{oc}[V]	40.9
Short circuit curant I_{cc}[A]	3.93
Voltage at maximum powerV_{mpp}[V]	30.4
Curant at maximum power I_{mpp}[A]	3.29
Efficiency η_m [%]	6.9
Number of cell	72
Module surface A_m[m²]	1.45
Inverter Specifications	
Manufacturer	SOLARMAX
model	S2000
DC nominal voltage Vin[V]	600
DC power Pdc[w]	2000
DC voltage range Vdc[V]	100-550
AC nominal power Pac[VA]	1980
Nominal AC voltage Vac[V]	230/184-300
Efficiency η_{ond} [%]	97

3.1 System Energy Output

The total daily $E_{(AC,d)}$ and monthly $E_{(DC,m)}$,$E_{(AC,m)}$ energy generated by the PV system is given by (Sharma V, et al.,2013):

$$E_{(AC,d)} = \sum_{t=1}^{24} \mathrm{E}_{(\mathrm{AC,t})} \qquad (1)$$

$$E_{(AC,m)} = \sum_{d=1}^{\mathrm{N}} \mathrm{E}_{(\mathrm{AC,d})} \qquad (2)$$

$$E_{(DC,m)} = \sum_{d=1}^{\mathrm{N}} \mathrm{E}_{(\mathrm{DC,d})} \qquad (3)$$

Where N is the number of days in the month, $E_{(AC,t)}$ is the instantaneous measured energy.

3.2 Inverter and System Efficiency

The instantaneous inverter efficiency is calculated as

(Chikh M et al.,2015):

$$\eta_{inv} = \frac{P_{ac}}{P_{dc}} \qquad (4)$$

Where the P_{dc} and, P_{ac} are respectively the DC and AC power.
The monthly system efficiency is calculated by

(Chikh M et al.,2015):

$$\eta_{sys} = \left(\frac{E_{(AC,m)}}{G_t} . A_m\right) . 100 \qquad (5)$$

Where G_t is the total in plane radiation (Wh/m²), and A_m the PV array area (m²).

3.3 Reference Yield(Yr)

The reference yield is the total in-plane solar insolation H_t (kW h/m²) divided by the array reference irradiance (1 kW/m^2) (Kymakis E, et al). This parameter represents the equal number of hours at the reference irradiance and is given by:

$$Y_r = \frac{H_t\left(\frac{kWh}{m^2}\right)}{1\left(\frac{kWh}{m^2}\right)} \qquad (6)$$

3.4 Array Yield (Ya)

The array yield Ya is defined as the energy output from a PV array over a defined period (day, month or year) divided by its rated power (Sharma V, et al.,2013) and is given by:

$$Y_a = \frac{E_{dc}(kWh)}{P_{pv,rated}(kWp)} \qquad (7)$$

3.5 Final Yield (Yf)

The final yield is defined as the annual, monthly or daily net AC energy output of the system divided by the rated power of the installed PV array at standard test conditions (STC) of 1 kW/m2solar irradiance and 25°C cell temperature. This is a representative figure that enables comparison of similar solar PV power plant in a specific geographic region. It is independent on the type of mounting, vertical on a facade or inclined on a roof and also on the location (Tripathi B, et al.,2014) and is given by:

$$Y_f = \frac{E_{ac}(kWh)}{P_{pv,rated}(kWp)(7)} \qquad (8)$$

3.6 Performance Ratio (PR)

The Performance Ratio (PR) is a measure of the quality of a PV plant that is independent of location. Therefore, it is often described as a quality factor. The (PR) is stated as percent rate and describes the relationship between the actual and theoretical energy outputs of the PV plant. It shows the proportion of the energy that is actually available for export to the grid after deduction of the energy loss (e.g. due to thermal losses and conduction losses) and of energy consumption for operation.

In real life, a value of 100 % cannot be achieved, because unavoidable losses always arise with the operation of the PV plant (e.g. thermal loss due to heating of the PV modules). High-performance PV plant scan however reach a performance ratio of up to 80 % (SMA Solar Technology AG)The PR is given by:

$$PR = \frac{Y_f}{Y_a} \qquad (9)$$

3.7 Capacity Factor

The capacity factor (CF) is a means to present the energy delivered by an electric power generating system. If the system delivers the full rated power continuously, its CF would be unity. The capacity factor (CF) is defined as the ratio of the actual annual energy output to the amount of energy that the solar PV power plant could generate if it is operated at full rate power ($P_{pv,rated}$)for 24 h per day for a year (Tripathi B, et al.,2014) and is given by:

$$CF = \frac{Y_f}{24 * 365} = \frac{E_{dc}}{P_{pv,rated}} * 8760 \qquad (10)$$

3.8 Array Capture Losses

The array capture losses (Lc) are due to the PV array losses and are given by (Ayompe L M, et al.,2010):

$$Lc = Yr - Ya \qquad (11)$$

3.9 System Losses

The system losses (Ls) are induced by the inverter and are given by (Ayompe L M, et al.,2010):

$$\boldsymbol{Ls = Ya - Yr} \qquad (\mathbf{12})$$

4 RESULTS AND DISCUSSION

4.1 Meteorological Data

The total irradiation received on the PV generator during the monitoring period is 833.55kWh/m². Figure 3 shows the evolution of the monthly solar energy received by the array which varies between 2.16 kWh/m².d recorded in January 2016 and 3.18 kWh/m².din September 2016. This variation is predictable considering the sun's trajectory relative to the PV field located in a vertical plane. The maximum irradiation was reached during the month of September which coincides with the beginning of the fall and which is favorable for the vertical inclinations.

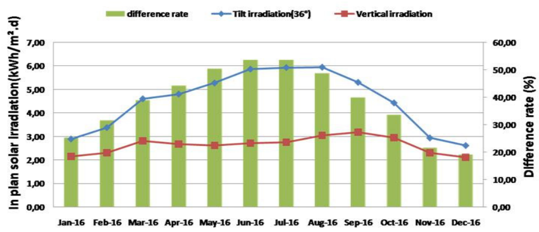

Figure 3: Monthly average daily irradiation respectively on the vertical plan of the PV array and on the optimal angle for the site (36°).

It could be noticed that the PV array on the vertical plane receives less solar irradiation than it could have received if it is installed on an inclined plane with an optimal angle of 36 ° for the site. The irradiation losses were the highest in June (53.71%) and the lowest in November (21.62%).
The ambient temperature of the site of BouIsmaïl doesn't exceed, the value 30 ° C all over the year and this is due to the specific Mediterranean climate of the location. The average monthly ambient temperature and the back module temperature during the monitoring period are shown in fig 4.
The average monthly ambient temperature varies between 14.65 ° C in March and 24.63 ° C in August, while the average monthly PV module temperature varies between 19.5°C in February and 31°C in July. Because of the fact that the temperature increase of the amorphous modules is only 10°C, it can be concluded that the influence of the temperature can be considered negligible. This is due to the low value of the temperature coefficient of the a-Si material.

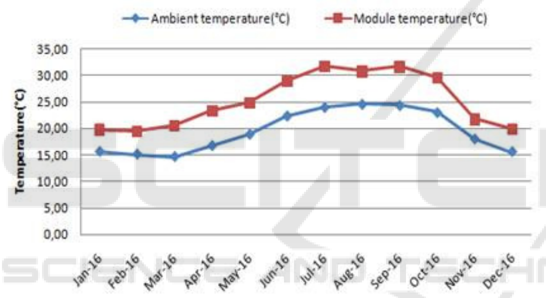

Figure 4: Monthly average ambient temperature and module temperature over the monitored period.

4.2 DC Power Input and Inverter Efficiency

Figure 5 shows the variation of the inverter efficiency with the DC power input for three months. It could be noticed that the inverter operates with stability when AC power input is greater than200W with an average efficiency of 90.2%. When the DC power input is under 200W, the efficiency decreases drastically due to the fact that the DC voltage of the PV array is not in the operating range of the inverter.

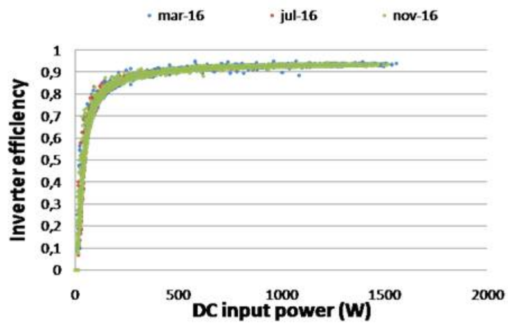

Figure 5: Inverter efficiency

4.3 Energy Output and PV System Efficiency

The output energy and the efficiency of the PV system are calculated using equations (2) and (3) respectively. During 12 months the PV system has produced about 850kWh, with an annual PV system efficiency of 4.76% which is in the range efficiency of the a-Si PV system. From the Figure 6, it could be seen that the monthly output energy and the PV system efficiency are mainly influenced by the solar irradiation received on the vertical plane during each month. Their values were comprised between (2.60kWh/d and 4.68%) in July and (3.90kWh/d and 5.65%) in March respectively.

4.4 Reference Yield, Array Yield and Final Yield

The reference yield (Yr), the array yield (Ya) and the final yield (Yf) of the studied a-Si PV plant are given in figure 7. It appears that the monthly values of reference yield Yr ranged between1.9 kWh/kWp.d in January and 2.82kWh/kWp.d in September.

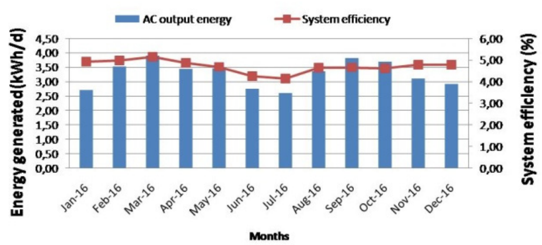

Figure 6: Monthly average AC output energy and efficiency of the a-Si PV system.

Ya varies between 1.28 kWh/kWp.d in July and 1.63 kWh/kWp.d in March and Yf varies between1.08

kWh/kWp.d in july and 1.59kWh/kWp.d in September. As expected, it could be seen from Figure 7 that for the a-Si PV array the temperature variation has less influence on the Yf than the irradiation.

4.5 Captures Losses and System Losses

Figure 8 shows the monthly average daily capture and system losses through the monitoring period. The capture losses (Lc) are very significant and vary between 0.64 h/d in January and 1.06 h/d in September. This is mainly due to two probable reasons.
The first one, which is obvious, is related to the vertical position of the PV plant which reduces hardly the amount of solar irradiation received.

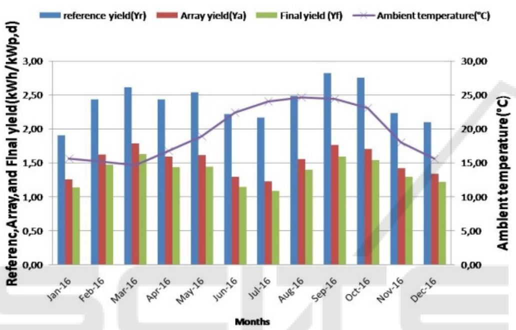

Figure 7: Monthly average daily system's final yield Yf,reference yield Yr and array yield Ya.

The second reason concerns the partial shading due to the holder structure of the modules and the vegetation (cf. Figure9).
However, the system losses are relatively low and ranged from 0.12h/d in January to 0.17 h/d in May and September, thanks to the good efficiency of the inverter.

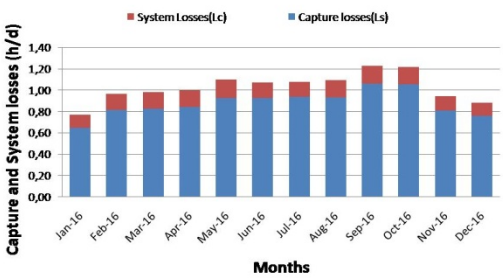

Figure 8: Monthly average capture and system losses

4.6 Performance Ratio and Capacity Factor

Figure 10 shows the results of PR and CF. The results showed that the PR varied between 0.51in July and 0.62 in March and it has an annual value of 0.57, meanwhile the CF varies between 4.53 % in January and 8.72 % in August with an annual value of 5.68%.

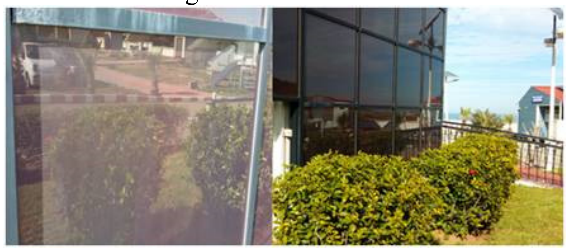

Figure 9: View of partial shading components around the PV plant system

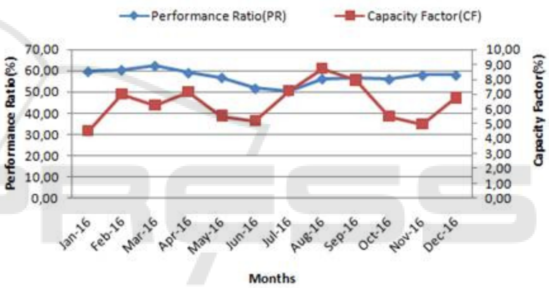

Figure 10: Performance Ratio and Capacity Factor of the a-Si PV system.

The results of works published in the IEA report on thin film systems show, that the performance of 14 thin PV systems installed on the facade have their PR ranged between 0.61 and 0.84 with an average of 0.72 (Lee H M, et al.,2016).
Compared to a-Si vertical PV installations appearing in Table 2, the UDES a-Si PV system has a slightly lower PR (0.57) compared to the (Lee H M, et al.,2016).and (Rustu E and Ali S,2013) facilities with a PR of 0.69 and 0.74 respectively. This is due to the reasons mentioned above namely the shading and the orientation of the strings of the PV plant.

Table 2: Performance comparison of different amorphous grid-connected PV systems in different locations.

Location	Installationtype	Cell type	Capacity (kWp)	PR	System efficiency (%)	réf
South Korea	vertical BIPV South facing	a-Si thin film (10%Transmittanc)	10.6	0.69	-	(Lee H M, et al.,2016).
Morocco	Rooftopinclined	a-Si/a-Si tandem	1.86	0.73	7.21	Amine H, et al.,2017)
Turkey	On twers (vertically installed)	a-Si Single junction	10.24	0.74	5.58	(Rustu E and Ali S,2013)
Turkey	Onfacade (60tilted)	a-Si Triple junction	30.15	0.81	5.99	(Rustu E and Ali S,2013)
Algeria	FacadeVertical South facing	a-Si/a-Si tandem	2.4	0.57	4.76	Present Study

5 CONCLUSIONS

The 2.4 kWp amorphous Silicon grid connected PV system facade mounted at BouIsmaîl, was monitored between January 2016 and December 2016, in the context of providing information on this type of facility in order to see their potential for the BAPV application. Its performances were evaluated and presented in this paper, the main conclusions are as follows:

- As the system is mounted on the facade, the losses of solar radiation are considered in comparison with the radiation received at an optimum inclination. Their values are 53% maximum in summer and 19% in winter.
- During the monitoring period the system supplied 850 kWh to the grid. This production is strongly related to the amount of radiation received, while the influence of the temperature is not noticeable.
- The average annual reference yield is 1.36 kWh/kWp.d and it reaches the maximum 2.82 kWh/kWp.din fall (September) and 1.9 kWh/kWp.din spring (May).
- Due to the poor design of the holder structure of the modules, the shadows caused by the obstacles in front of the PV field and the vertical position of the PV field, the capture losses are high(0.88h/d). In contrast,the system losses are negligible(.0.139h/d).
- During the monitoring period the system contributed to the decrease of the CO2 emissions by 510 kg (Lee H M, et al.,2016).

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